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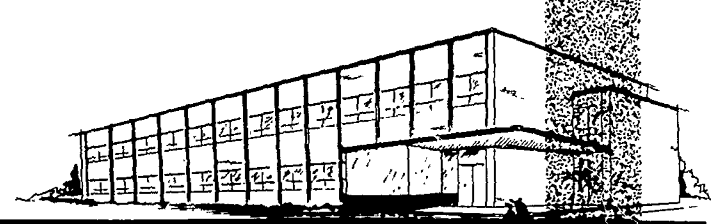

THE Bendix CORPORATION

BENDIX SYSTEMS DIVISION • ANN ARBOR MICHIGAN

BSC-37051

STUDY TO DETERMINE EFFECTS OF
FISSION PRODUCT GAMMA RADIATION ON
ELECTRONIC PARTS AND EQUIPMENT (U)

By R. M. Magee and D. A. Courtois

PROGRESS REPORT NO. 4
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CONTRACT NO. NObsr-87267
For Bureau of Ships

The results of these tests shall not be circulated, referred to, or otherwise used for publicity or advertising purposes or for sales other than those leading to ultimate use by any agency of the Federal Government.

MARCH 1963

BENDIX SYSTEMS DIVISION
of
THE BENDIX CORPORATION
Ann Arbor, Michigan

ABSTRACT

The effects of gamma radiation on circuit cards from the Naval Tactical Data System Shipboard Computer and associated equipment have been investigated. During this reporting period five types of circuit cards were tested in a gamma ray environment up to 3×10^5 r/hr, and up to total exposures of 1.5×10^4 r. A total of twelve circuit card types have been tested in this radiation environment during the contract period. No significant radiation effects have been observed on the performance of any of these circuit cards.

ADMINISTRATIVE INFORMATION

The work under this contract has been performed in accordance with Navy Specification SHIPS-S-4006 dated 6 October 1961, Work Statement No. 1, received 1 June 1962, and Work Statement No. 2, received 22 October 1962.

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SECTION 1

INTRODUCTION

The general purpose of this program is to investigate the effects of gamma radiation on electronic parts and equipment. Semiconductor digital circuits were selected for these investigations. The first two work statements required active tests of AN/USQ-20 (which is part of the Naval Tactical Data System) computer circuit cards in a cobalt-60 gamma radiation environment. Two dose-rate time curves were specified; tests are required at 70° and 100°F. Eight samples of each of the twelve types of circuit cards have been provided by the technical contacts at USNRDL. The required tests are as follows:

1. Two cards of each type at 100° following the high dose rate curve
2. Two cards of each type at 70° following the high dose rate curve
3. Two cards of each type at 70° following the low dose rate curve.

During this report period tests were completed on five types of circuit cards at the University of Michigan Phoenix Memorial Laboratories. Previously, seven other types of circuit cards were tested to give a total of twelve types of cards to date.

The test approach has been to determine if the circuit cards operate within the manufacturer's acceptance specifications while in the required radiation-temperature environment. Therefore the circuit card manufacturer's test procedures have been followed whenever possible. However, the added requirement of remote monitoring, and recording of data at appropriate intervals during a test, made necessary some modifications of the manufacturer's test procedures. This approach provides a basis for judgment of whether the circuit performance would have caused the equipment to malfunction if the entire system had been in the radiation environment.

The card types which were tested during the past quarter have been given the following letter designations in this report. (Schematics for the cards are shown in Section 5).

Card Type	Circuit Title
1. B	Inverter—Heavy Duty
2. E	Amplifier, Driver—Data Time
3. H	Amplifier, Driver—Read/Write Current
4. K	Double Inverter—Inhibit Current Diverter
5. L	Amplifier, Driver—Transformer Enabler

The individual cards were given numerical designations, and cards of each type with the same number were tested in the same environment. The numerical code used is as follows:

Card Number	Use
1 and 2	Test set-up and reference
3 and 4	Tested at 100°F and high dose rate curve
5 and 6	Tested at 70°F and high dose rate curve
7 and 8	Tested at 70°F and low dose rate curve

Figures 1-1 through 1-5 show the test and instrumentation setup. Two cards were tested simultaneously in the center of the cylindrical test volume. When the cobalt-60 rods, which are in a ring configuration, are raised, they occupy the outer position of the cylinder shown. Also shown are cathode-follower circuits which were used to provide impedance matching with the long cables that are required for remote monitoring of circuit performance.

Figure 1-1 General View of Instrumentation

Figure 1-2 Recorders Showing Method Used for Controlling Gamma Dose Rate

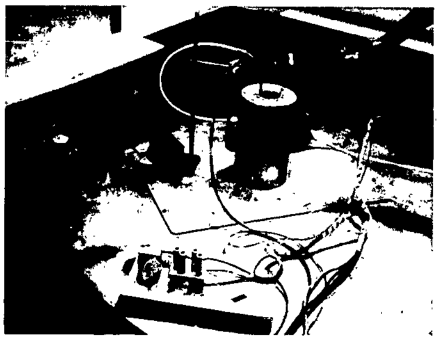


Figure 1-3 General View of Irradiation Area Showing Test Cylinder, Circuit Card Holder, and Cathode Followers

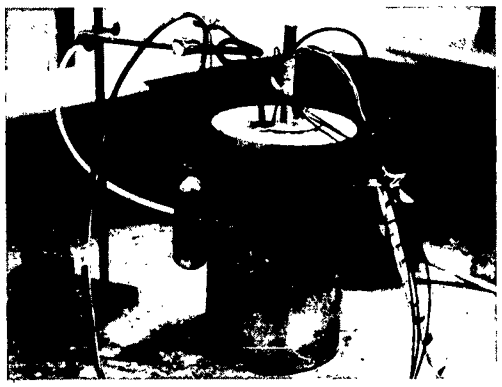


Figure 1-4 Experiment in Place With The Ion Chamber Outside The Test Cylinder

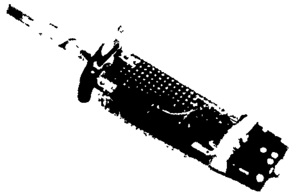


Figure 1-5 Circuit Card Holder With Two Typical Cards

SECTION 2

DOSIMETRY

Two dosimetry techniques were employed during the tests. An ionization chamber was used to measure the dose rate during irradiation. The variation of the source position to match the dose rate vs time curve was based on measurements with this chamber. The total dose during irradiation was measured with cobalt glass dosimeters. Results from the two different measurement techniques generally show good agreement.

2.1 IONIZATION CHAMBER

The ionization chamber used is a Lockheed Model 504. This is a carbon-wall chamber, filled with CO_2 to a pressure of approximately one atmosphere. The ion chamber is operated at 400 volts, which ensures operation at the ion collection saturation voltage at the highest dose rate (3×10^5 r/hr) required for these tests.

The response of the ion chamber (in amperes) is theoretically linear with gamma dose rate over the entire ion chamber range. This has been verified for the particular ion chamber used in these tests for the ranges of 100 r/hr to 5×10^5 r/hr. The ion chamber output current is measured with a Keithley Model 401 Micromicroammeter, whose output is recorded on a Texas Instruments Recti/Riter.

2.2 COBALT GLASS DOSIMETERS

The total gamma dose is measured with a Bausch and Lomb glass dosimetry system, which uses small slides of F-0621 cobalt glass and a Spectronic 20 Colorimeter. The glass samples are 15 x 6 x 1.5 mm in size. The change in absorption coefficient of the glass is a linear function of gamma dose over the range of 10^3 r to 10^6 r. The application of this glass in gamma ray dosimetry has been described in the literature (References 1, 2, page 2-2).

In practice, the transmission of a number of unirradiated glass samples is measured on the Colorimeter to find an adequate number of samples whose transmissions are the same. One of these is reserved as a standard for post-irradiation measurements, and the others are exposed during the test. The transmission is measured at a wavelength of 4000 Å, and the dose rate is taken from the calibration curve given in Reference 1.

The relative change in the transmission of this glass is a function of both the gamma dose and the glass thickness. For a single glass sample, the change for the low dose rate curve (total dose of about 3000 r) is only about 2%, which gives a poor relative accuracy. In order to improve this accuracy, pairs of glass samples are used for monitoring the low dose rate tests. Figure 2-1 shows the calibration curves for a single glass sample (t = 0.15 cm) and a pair of glass samples used together (t = 0.30 cm).

The results of the cobalt glass measurements for the tests performed during the past quarter are given in Table 2-1. The values measured for the high dose rate runs are generally within about 20% of the desired total dose, with the largest variation from the specified dose being about 40%. For the low dose rate runs, almost all of the values are low, in one case by as much as a factor of two. This indicates that the dose received by the cards during these runs was generally somewhat less than the desired value of 3000 r. Two glass samples, one bare and one shielded with 0.06 cm of copper, were included in most of the runs. The copper shielding had no consistent effects on the measured dose, indicating that there was no appreciable contribution from scattered radiation.

REFERENCES, SECTION 2

1. W. T. K. Johnson, "Extended Applications of a Cobalt Glass Dosimeter," presented at the 1962 Summer General Meeting of AIEE, June 1962.

2. N. J. Kreidl and G. E. Blair, "Recent Developments in Glass Dosimetry," Nucleonics, Vol. 14, No. 3, pp 82-83, March 1956.

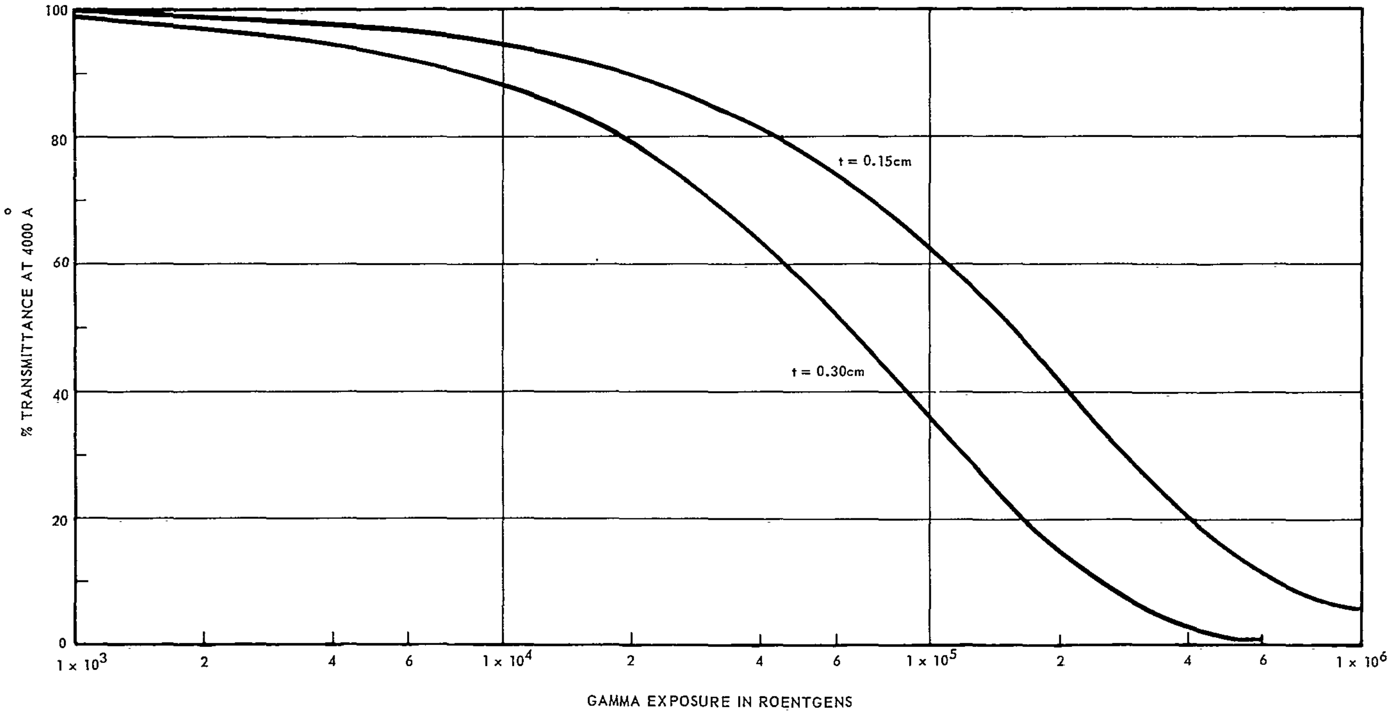


Figure 2-1 Calibration Curves for Cobalt Glass Dosimeters

TABLE 2-1

MEASURED GAMMA RAY DOSES

Circuit Cards Tested	Low or High Dose Rate Curve	Measured Dose (roentgens)
H-3, H-4	H	1.7×10^4
		1.4×10^4(S)
H-5, H-6	H	1.3×10^4
		1.5×10^4(S)
H-7, H-8	L	2.3×10^3
		1.5×10^3(S)
E-3, E-4	H	1.3×10^4
		1.3×10^4(S)
E-5, E-6	H	1.5×10^4
		1.1×10^4(S)
E-7, E-8	L	1.4×10^3
		2.6×10^3(S)
L-3, L-4	H	1.8×10^4
		2.0×10^4(S)
L-5, L-6	H	1.9×10^4
		1.9×10^4(S)
L-7, L-8	L	1.9×10^3
		3.0×10^3(S)
K-3, K-4	H	1.5×10^4
		1.6×10^4(S)
K-5, K-6	H	1.7×10^4
		1.3×10^4(S)
K-7, K-8	L	2.0×10^3
		1.9×10^3(S)
B-3, B-4	H	2.1×10^4
		2.0×10^4(S)
B-5, B-6	H	1.6×10^4
		2.0×10^4(S)
B-7, B-8	L	2.2×10^3
		3.4×10^3(S)

(S) Denotes glass sample shielded by 0.06 cm of copper.

SECTION 3

DOSE RATE CONTROL

Figure 3-1 shows the desired radiation intensity vs time characteristic for the high dose rate curve. This curve can be considered as made up of 25 stops at various dose rates. The duration of the stops are from 10 seconds at stop number 1, to 170 seconds at stop number 18. The maximum dose rate is 3×10^5 r/hr at stop number 14, and the minimum dose rate is 1.4×10^3 r/hr at stop number 1.

Figure 3-2 shows the desired radiation intensity vs time characteristic for the low dose rate curve. This curve is made up of 24 stops at various dose rates from a minimum of 7.8×10^2 r/hr to a maximum of 6.0×10^4 r/hr.

The University of Michigan cobalt-60 source is stored under water and raised by an elevator for irradiations. The elevator motor is manually controlled by a three-position switch located outside the test cell. The elevator operator can raise the source, lower the source, or stop and hold the source at any level. With the source all the way up, the maximum dose rate at the center of the test volume is 5.0×10^5 r/hr which is greater than the maximum required for the high dose rate curve. To change dose rate, the source had to be raised and lowered to correspond to the stops on the desired dose rate curve, without ever actually raising the source all the way up. To accomplish this, the ionization chamber was used to monitor the actual dose rate during irradiation. The elevator operator was able to stop at the proper dose rates for the required number of seconds by monitoring the output from the micromicroammeter.

The micromicroammeter has an output of 5 volts for full scale deflection on all of its ranges. During irradiation tests, this output was recorded as a measure of the actual dose rate. This same 5-volt output was used to drive an indicator for the elevator operator.

The indicator that the elevator operator watched was a modified Varian Recorder, Model G11A. The pen on this recorder was replaced

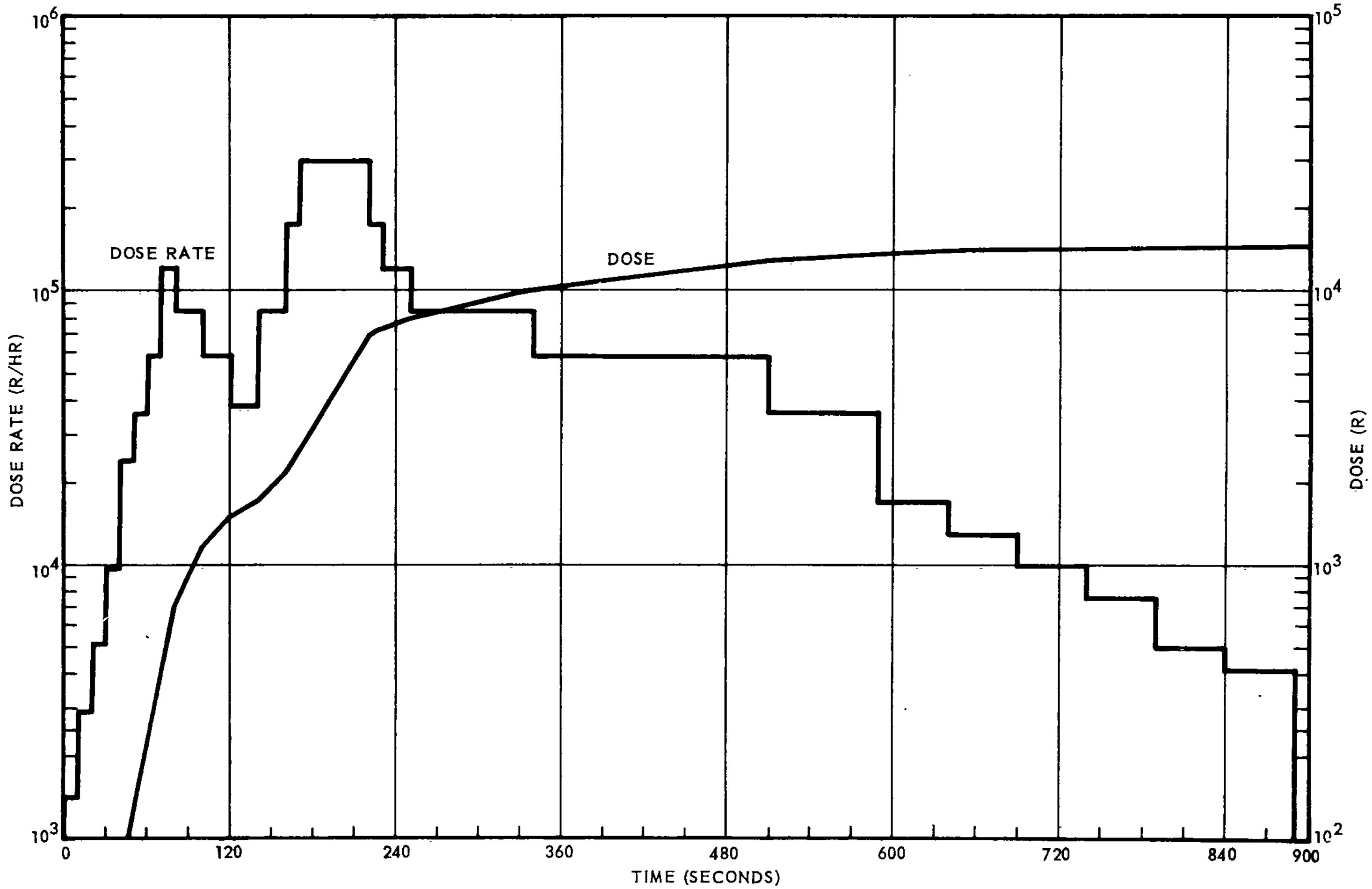


Figure 3-1 Desired High Dose Rate and Dose Curve

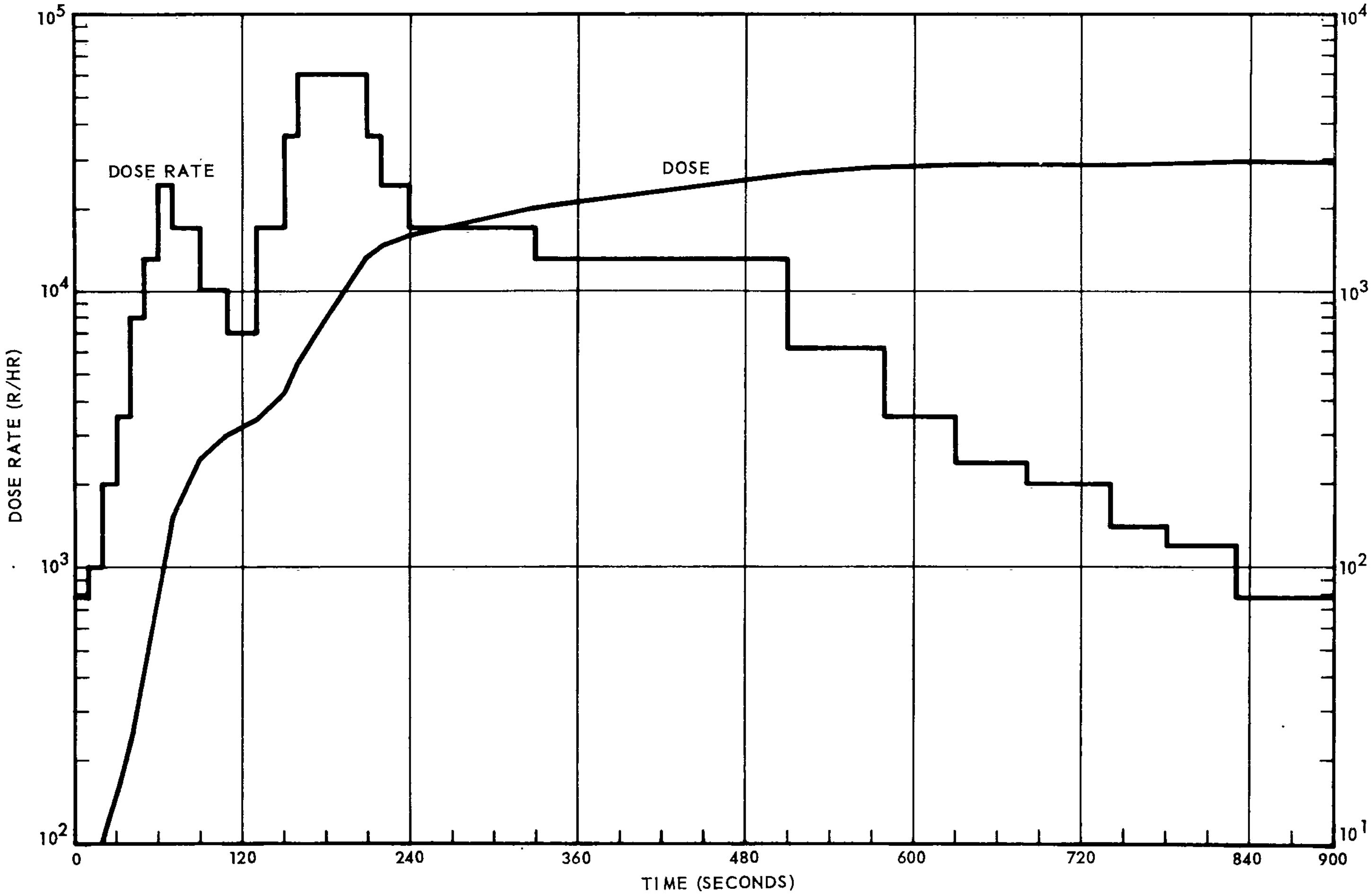


Figure 3-2 Desired Low Dose Rate and Dose Curve

by a pointer and the sensitivity was adjusted to give exactly 5 volts full scale. Two program charts were then pre-drawn, one corresponding to the high dose rate curve and the other to the low dose rate curve. To control the dose rate for a test run, one of these program charts was placed on the modified recorder. The elevator operator's job was then one of raising or lowering the cobalt source to keep the pointer on the program line.

SECTION 4

TEMPERATURE CONTROL

To ensure that thermal effects would not obscure the radiation effects, the test chamber temperature was not allowed to vary more than ± 2°F. The actual temperature seldom varied more than ± 1°F during a test run. Possible temperature effects were investigated by conducting some circuit card irradiations at an ambient temperature of 70°F and some at an ambient temperature of 100°F.

The manual temperature control system consists of a heating element with a variable voltage applied working against a constant amount of cooling air. The ambient temperature is continuously monitored using a thermistor connected to a resistance bridge. The cooling air is obtained from a compressed air line and passed through a heat exchanger which consists of a coiled copper tube immersed in an ice bath. The air temperature at the discharge of the heat exchanger is approximately 35°F. The cooled air then passes through a moisture condensation reservoir and through polyethylene tubing to the test chamber. If the air leaving the heat exchanger is saturated with water vapor at 35°F, this same air when heated to 70°F contains only 30% relative humidity, and at 100°F contains only 12% relative humidity. The process of first cooling the air and then heating it provides a means of maintaining a low relative humidity and a constant temperature.

SECTION 5

CIRCUIT CARD IRRADIATIONS

5.1 TYPE B CARDS (INVERTER-HEAVY DUTY)

5.1.1 Test Description

The Type B card has four single-stage inverters with germanium PNP 150 milliwatt alloy junction transistors. The schematic is shown in Figure 5-1. A negative input pulse causes the transistor to go from the off condition into saturation.

Figure 5-2 is the complete instrumentation for the B card tests. The crossbar switch allows the input signal to be connected in sequence to each of the eight inverters on the two cards and the outputs displayed in sequence on the oscilloscope. Cathode followers were used to buffer the card outputs and drive the coaxial cables. Measurements were made for the DC level of output signal for reference purposes, since the card specifications are in terms of DC levels. Resistors and capacitors were required at the cards for termination of the coaxial lines, proper card loading, and isolation of the pulse and DC measurements.

The input and output pulse waveforms have the following maximum requirements:

	Width (μ sec)	Amplitude (Volts)	Rise Time (μ sec)	Fall Time (μ sec)	Leading Edge Delay* (μ sec)	Trailing Edge Delay* (μ sec)
Input	2.0	-3.6	.025	.025	- -	- -
Output	- -	+15**	1.0	2.0	2.0	3.0

* Delays are measured from the 50% amplitude of the leading edge of the input to the 90% amplitude of the leading edge of the output, and from the 50% amplitude of the trailing edge of the input to the 10% amplitude of the trailing edge of the output.

** -15 volt DC reference

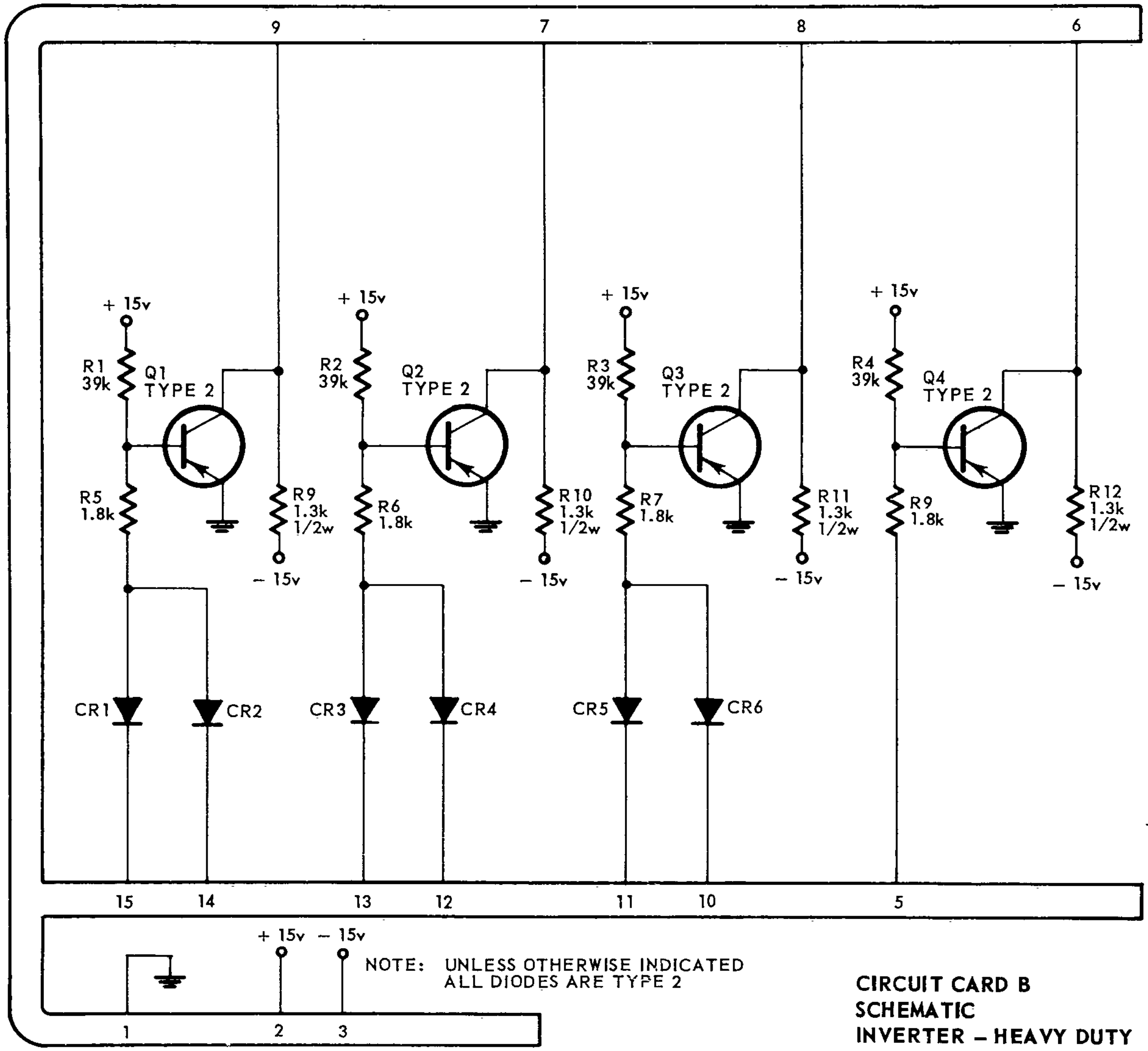


Figure 5-1 Inverter-Heavy Duty Schematic

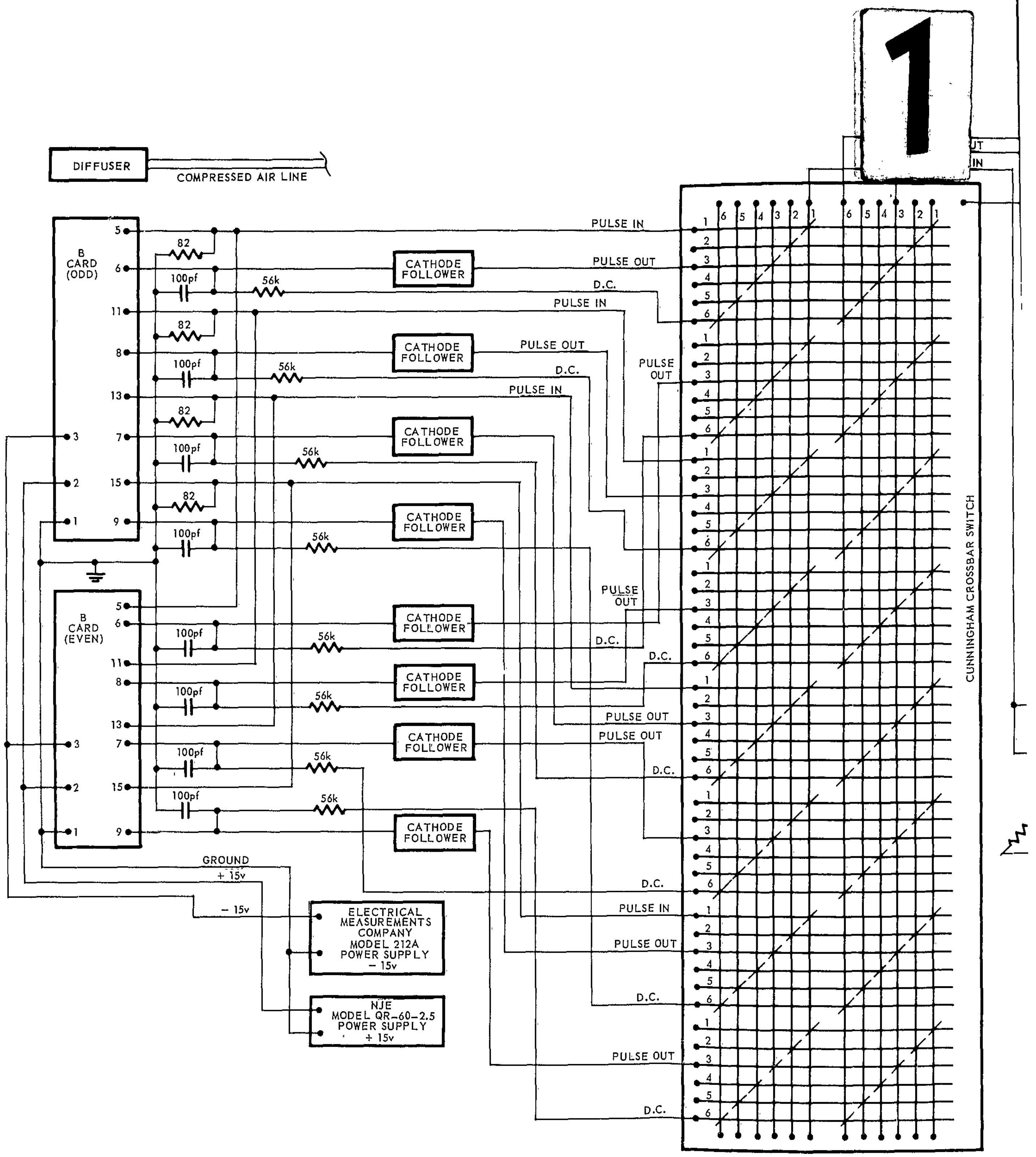

DIFFUSER
COMPRESSED AIR LINE
B CARD (ODD)
B CARD (EVEN)
82
100pf
56k
CATHODE FOLLOWER
PULSE IN
PULSE OUT
D.C.
GROUND
+ 15v
− 15v
ELECTRICAL MEASUREMENTS COMPANY MODEL 212A POWER SUPPLY − 15v
NJE MODEL QR-60-2.5 POWER SUPPLY + 15v
CUNNINGHAM CROSSBAR SWITCH
1

Figure 5-2 Ty

2

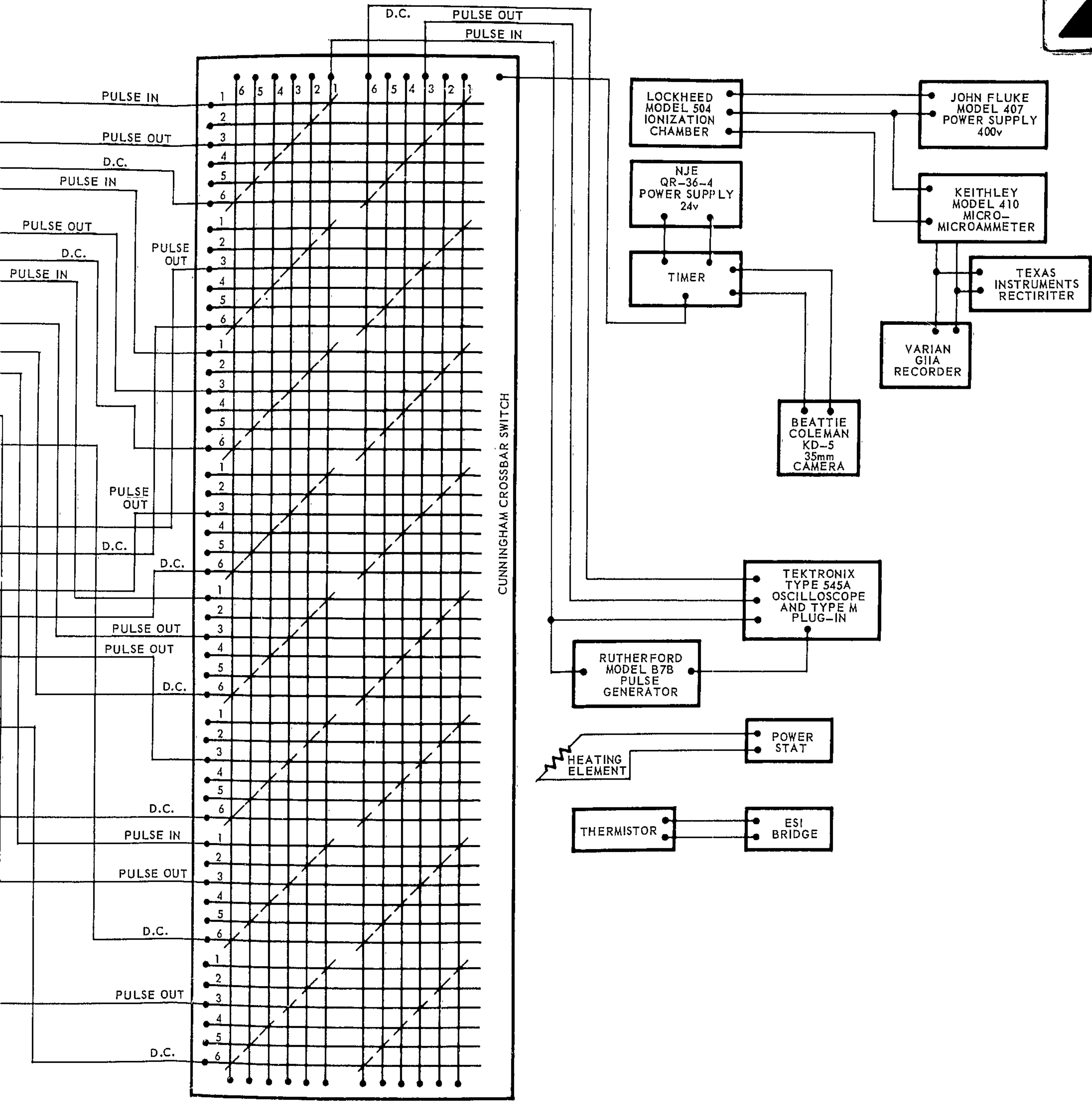


Figure 5-2 Type B Card Instrumentation

5.1.2 Test Results

The only measurable change in the output pulse characteristics was the position of the output trailing edge with respect to the position of the trailing edge of the input pulse. Typically the trailing edge delay increased 0.01 to 0.02 μ seconds. Delay increases up to 0.12 μ seconds occurred on some of the inverters on cards B3 and B4 (tested in the high dose rate environment at 100°F). This change was small compared to the total delay times and in no instance did the total delay measure as much as 2.0 μ seconds. A trailing edge delay of 3.0 μ seconds is allowed. No changes were noted in rise or fall times, and the changes in delay are probably changes in storage time due to transistor gain changes. The delay changes for each card are listed in Table 5-1.

Figure 5-3 shows a typical scope photograph of the waveforms of each of the card types tested. Some 340 photographs were taken of the inverter waveforms during the tests of six B-cards. The photograph shown is typical for all of the B-cards. The small waveform changes that did occur cannot be exhibited in positive prints suitable for a report. The waveform changes could be detected by projecting the photographs of the test results on a screen to many times their actual size. It is then possible to compare successive waveforms with the pretest waveform, and measure small changes (on the order of 0.01 μ seconds for a 2.0 μ second pulse width).

5.2 TYPE E CARDS (AMPLIFIER, DRIVER-DATA LINE)

5.2.1 Test Description

The E-card is a data line driver with a controlled slow rise and fall time output. Both PNP and NPN germanium alloy junction transistors are used. Figure 5-4 is the card schematic. The card connection scheme and switching are shown in Figure 5-5. The rest of the instrumentation was very much like that shown in Figure 5-2. The pulse waveform maximum requirements are as follows:

	Width (μ sec)	Amplitude (Volts)	Rise Time (μ sec)	Fall Time (μ sec)	Trailing Edge Delay (μ sec)
Input	20 to 25	-3.6	.025	.025	- -
Output	- -	+15*	4.0	4.0	6.0

* -15 volt DC reference

TABLE 5-1

MAXIMUM POSITIONAL CHANGES OF THE B-CARD TRAILING EDGE DURING IRRADIATION[1]

Card No.	Inverter No.	Maximum Positional Changes μ Seconds
B3	1	0.02
	2	0.12
	3	none
	4	0.1
B4	1	0.06
	2	0.12
	3	0.01
	4	0.04
B5	1	0.05
	2	none
	3	none
	4	0.01[2]
B6	1	0.02[3]
	2	none[4]
	3	none[4]
	4	none
B7	1	0.01
	2	0.01
	3	none
	4	none
B8	1	none
	2	0.01[2]
	3	0.02
	4	none

[1] Unless indicated the positional change was an increase in the time interval between the trailing edge of the input pulse and the trailing edge of the output pulse.

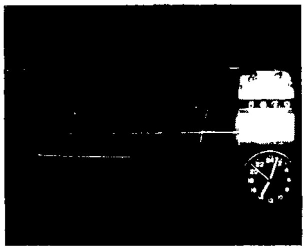
[2] Decrease in time interval

[3] Increase occurred during post tests

[4] Time interval decreased 0.02 and then increased 0.02 for a net of zero.

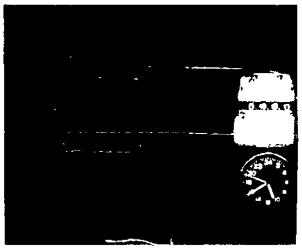
TYPE B CARD

SWEEP SPEED: 0.5μsec/cm



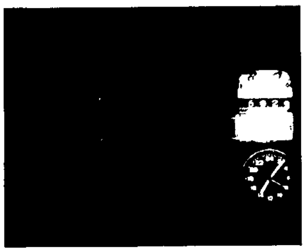
TYPE E CARD

SWEEP SPEED: 5.0μsec/cm



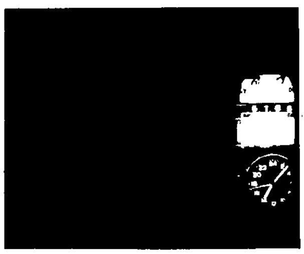
TYPE H CARD

SWEEP SPEED: 0.5μsec/cm



TYPE K CARD

SWEEP SPEED: 0.5μsec/cm



TYPE L CARD

SWEEP SPEED: 0.5μsec/cm

Figure 5-3 Typical Waveforms

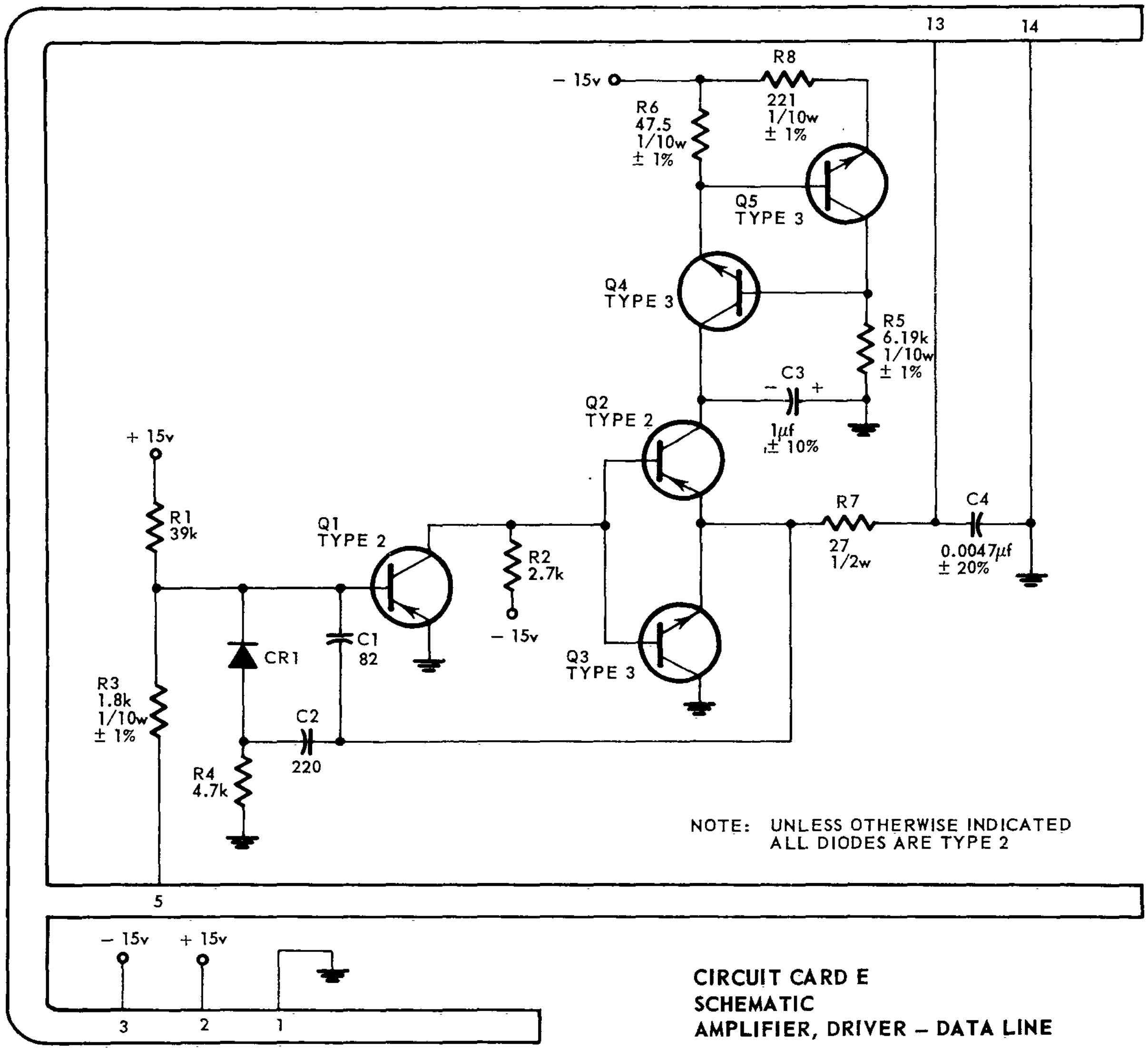


Figure 5-4 Amplifier, Driver-Data Line Schematic

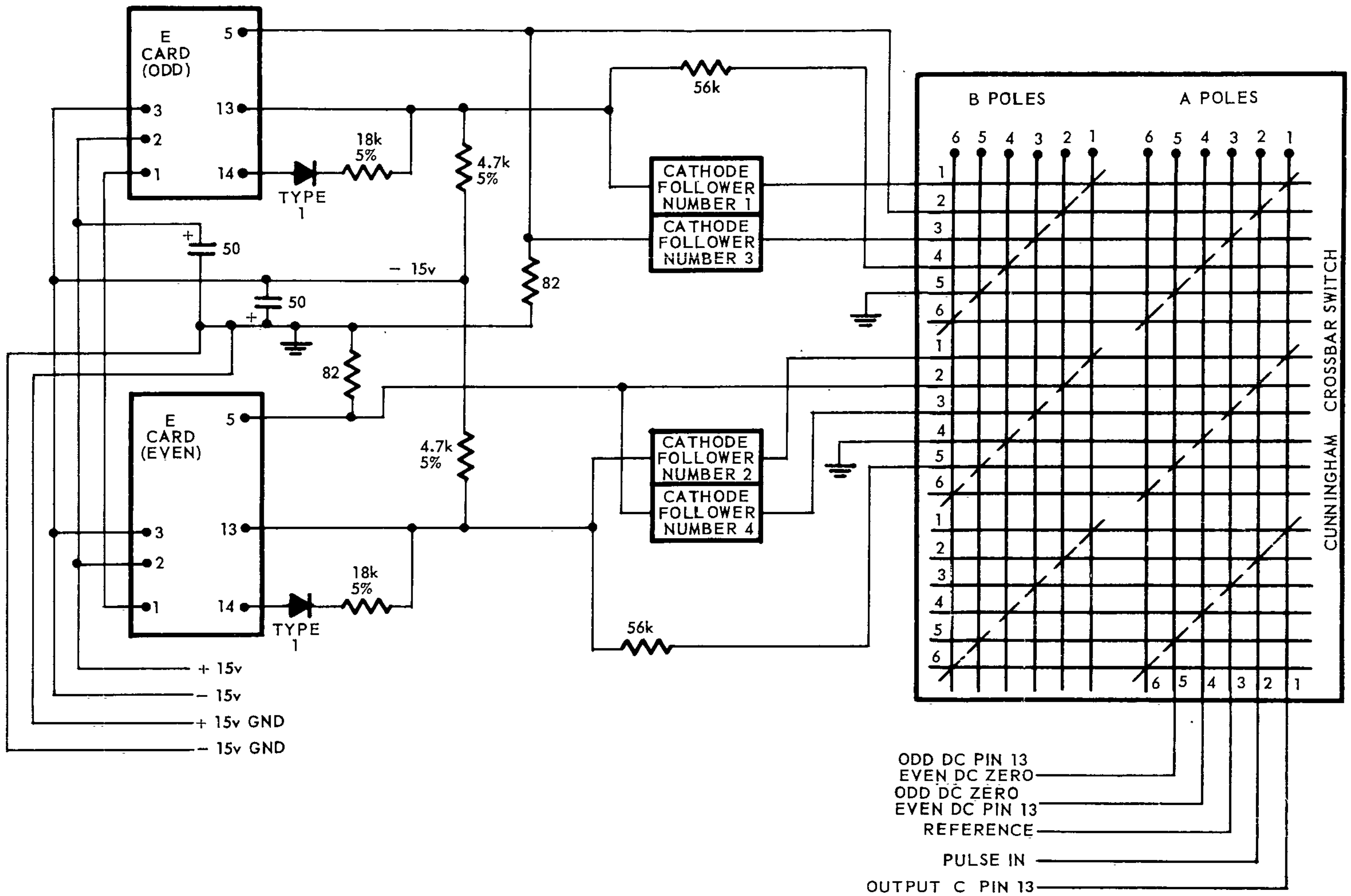


Figure 5-5 Type E Card Instrumentation

5.2.2 Test Results

The output of each card under test was photographed at each of the 24 or 25 dose rate levels. Figure 5-3 shows a typical waveform photograph for this card. About 212 photographs were taken of the waveforms including pre and post-test measurements. There were no measurable changes in the waveforms of any of the six cards tested.

5.3 TYPE H CARDS (AMPLIFIER, DRIVER-READ/WRITE CURRENT)

5.3.1 Test Description

The H card has three inverters in a series arrangement. The test conditions call for one input and one output pulse. Figure 5-6 is the circuit schematic. A negative pulse turns the first and third stages on. The instrumentation set up was very similar to that shown for the E card in Figure 5-5. Card pins 8, 12, 13, and 14 were connected to the common wire and a 110 ohm load resistor was connected between pin 9 and the -15 volt bus. The input pulse was applied to pin 15, and the output was on pin 9. Following are the input and output maximum pulse waveform requirements:

	Width (μsec)	Amplitude (Volts)	Rise Time (μ sec)	Fall Time (μ sec)	Leading Edge Delay (μ sec)	Trailing Edge Delay (μ sec)
Input	2	-3.6	.025	.025	--	--
Output	--	+15*	0.5	0.8	1.0	1.3

* -15 volt DC reference

5.3.2 Test Results

These cards showed very few effects from the radiation. The trailing edge delay on cards H4 and H5 increases less than 0.1 μ seconds during the irradiation. This change did not add significantly to the typical delays of less than 0.5 μ seconds, considering the specification requirement maximum of 1.3 μ seconds. There were no other measurable changes in pulse shapes in the 200 photographs examined.

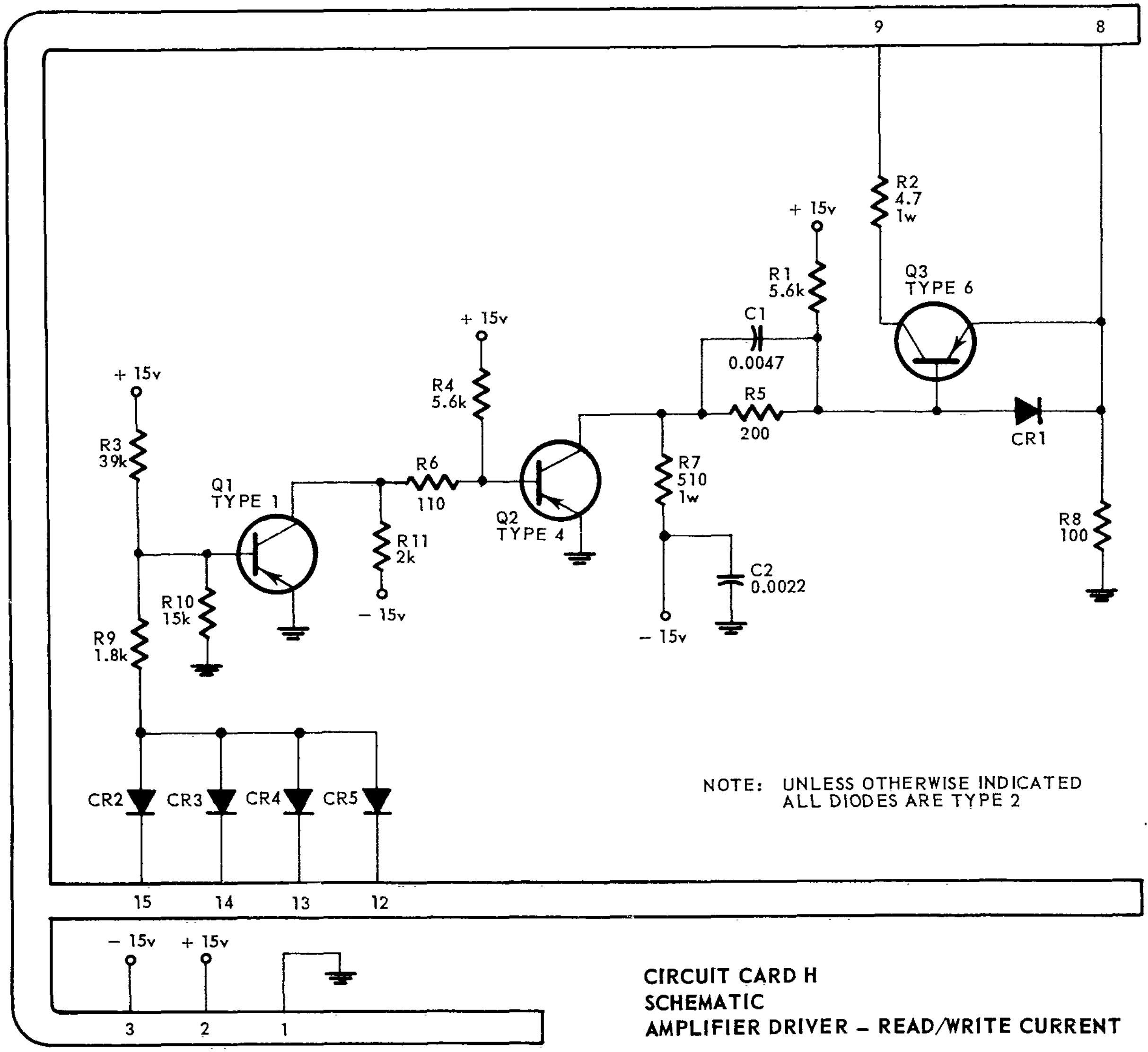


Figure 5-6 Amplifier Driver-Read/Write Current Schematic

5.4 TYPE K CARDS (DOUBLE INVERTER - INHIBIT CURRENT DIVERTER)

5.4.1 Test Description

The type K card has two inverters in series with a single input and several outputs. Figure 5-7 is the schematic. With zero volts input the first stage is off and the second is in saturation. With the external load and bias resistors shown in Figure 5-8 the output at pin 15 is -3 volts with zero input. The other input level is -5 volts; the second stage is then cut off. The output level at pin 15 is then set by the external circuitry at -10 volts.

The outputs at pins 10 and 11 are the same basic waveform with slightly different bias conditions and were not recorded in this test. The third step in the switching sequence allows the scope drift to be measured by grounding the input to trace B and driving the other traces off the presentation. This permits an accurate measurement of the pin 15 DC level. Following are the maximum waveform requirements:

	Width (μ sec)	Amplitude (Volts)	Rise Time (μ sec)	Fall Time (μ sec)	Leading Edge Delay (μ sec)	Trailing Edge Delay (μ sec)
Input	3**	-5.0	.05	.05	--	--
Output	--	-7*	--	--	.180	.10

*-3 volt DC reference

**A 2 μ second pulse width was used for the tests.

5.4.2 Test Results

More than 200 photographs of K card waveforms were examined, and no measurable changes were observed during the three irradiation runs. Figure 5-3 shows a typical photograph of the oscilloscope recording during these tests.

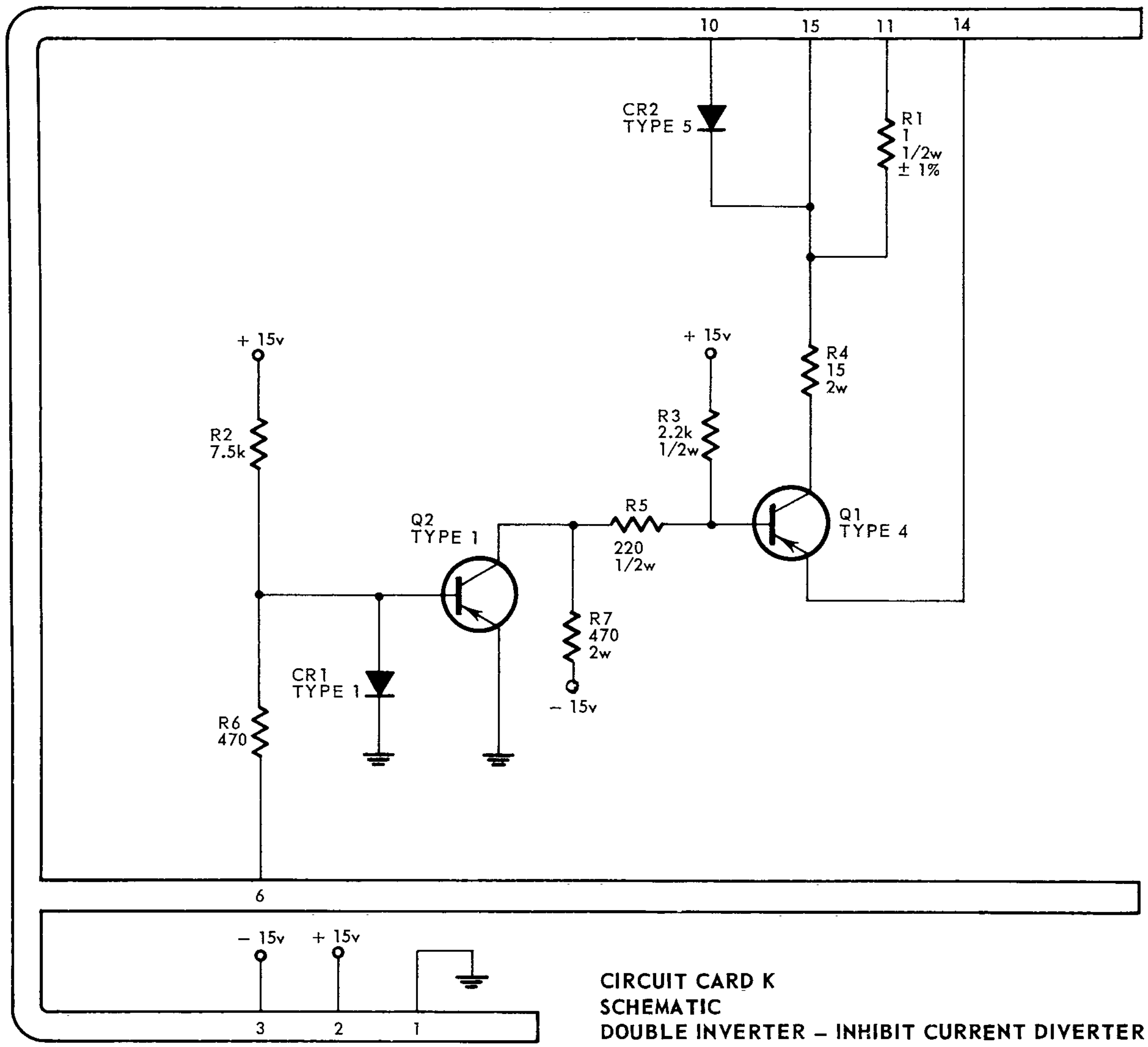


Figure 5-7 Double Inverter-Inhibit Current Diverter Schematic

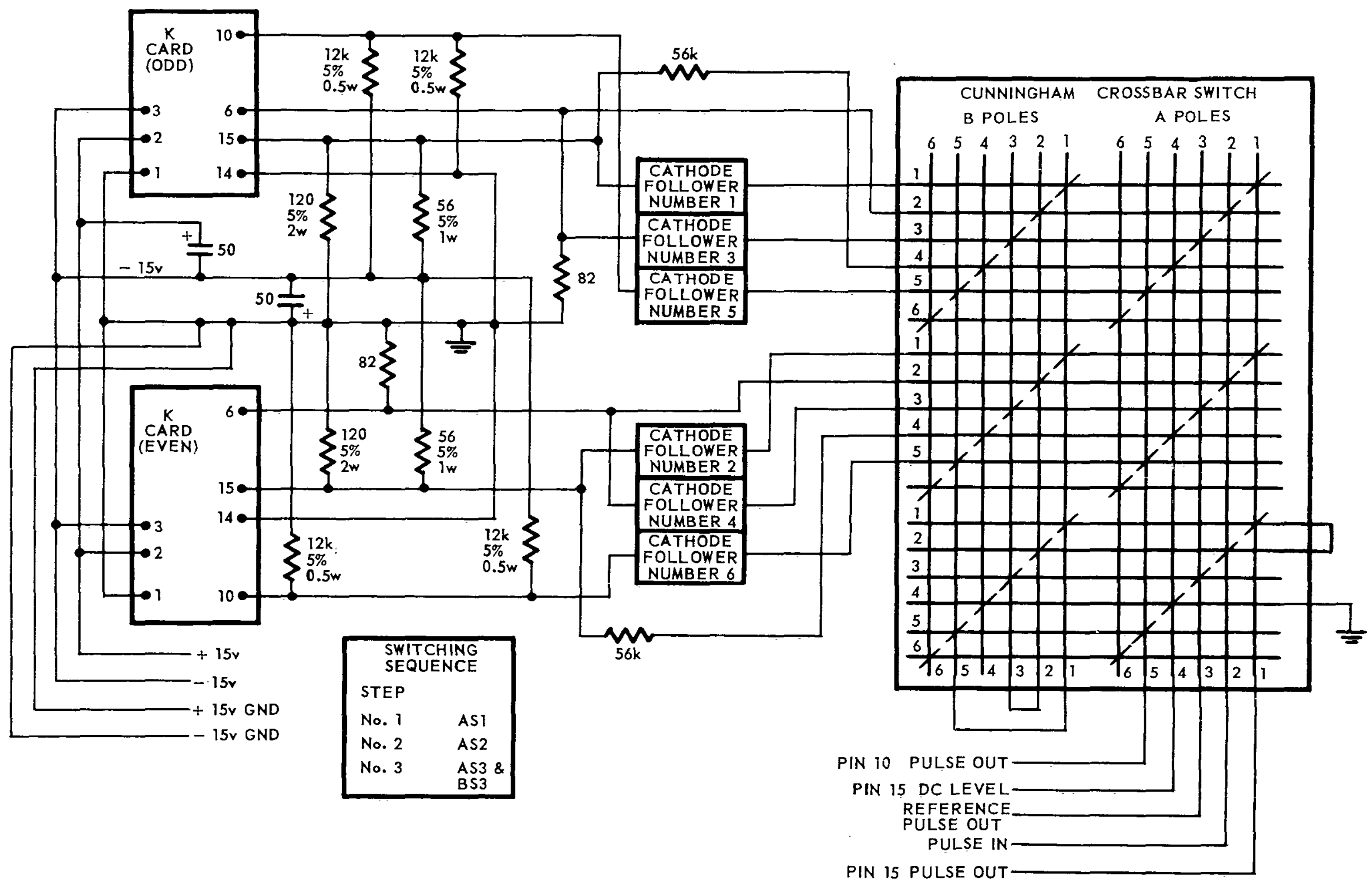


Figure 5-8 Type K Card Instrumentation

5.5 TYPE L CARDS (AMPLIFIER, DRIVER-TRANSFORMER ENABLER)

5.5.1 Test Description

The L card has two inverters each of which controls two gates. Figure 5-9 is the card schematic. Two test conditions are specified. In the first test configuration the gating transistor is turned on by a positive pulse applied to the emitter (pin 8, 10, 14, or 15). In the second test configuration, a negative potential on pin 5 or 6 holds the inverters off, and the gating transistors are operated in the active region with a current limiting resistor in the emitter circuit. In this second configuration, the test specifications call for measurements of emitter DC voltage. Because of the two loading conditions and the mixed pulse and DC test it was not feasible to run a two-phase test on this card. Instead the first half of the card was operated in the first test configuration, and the second half in the second test configuration. Figure 5-10 shows the instrumentation set up.

The waveform requirements for the first test configuration are as follows:

	Width (μ sec)	Amplitude (Volts)	Rise Time (μ sec)	Fall Time (μ sec)	Leading Edge Delay (μ sec)	Trailing Edge Delay (μ sec)
Input	2	+10	.025	.025	- -	- -
Output	- -	+10*	- -	- -	.05	.10

*DC reference is -10 volts

5.5.2 Test Results

Due to the two different types of tests, a four step test was required to test two cards. Each photo shows the following waveforms:

Trace A: Pulse into pin 8 or 10

Trace B: DC reference for output, pin 7 or 9

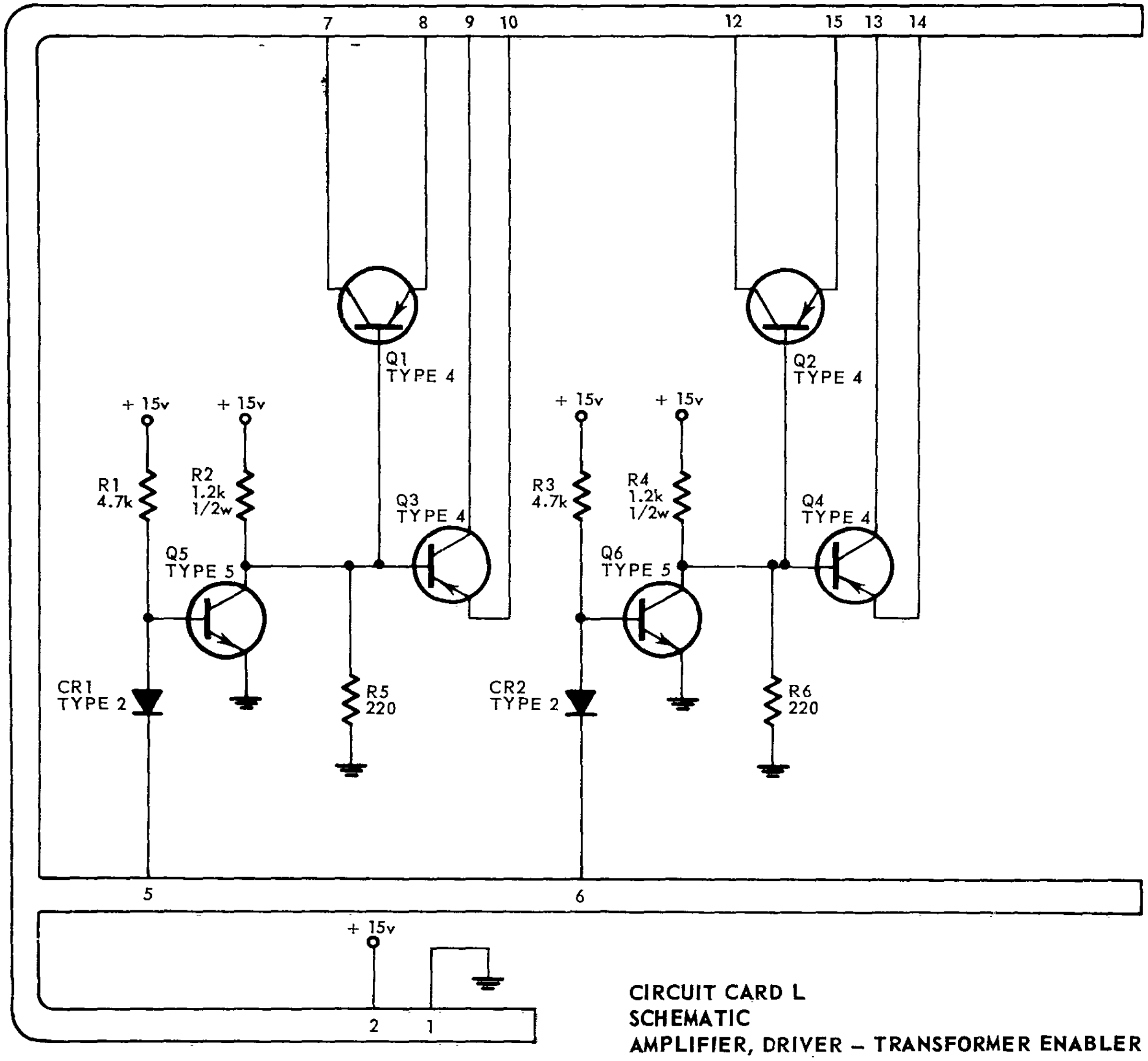


Figure 5-9 Amplifier, Driver - Transformer Enabler Schematic

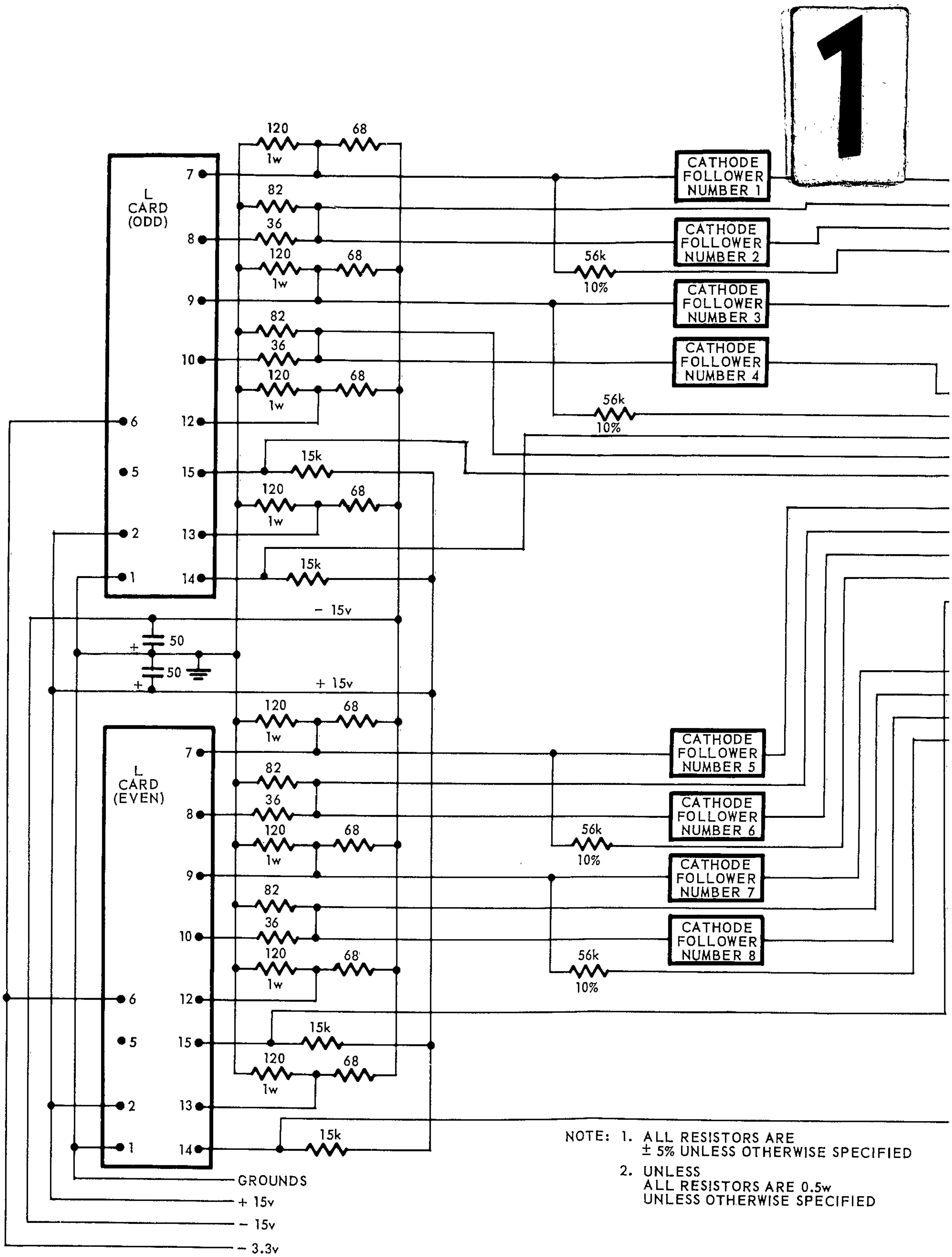

L CARD (ODD)
L CARD (EVEN)
CATHODE FOLLOWER NUMBER 1
CATHODE FOLLOWER NUMBER 2
CATHODE FOLLOWER NUMBER 3
CATHODE FOLLOWER NUMBER 4
CATHODE FOLLOWER NUMBER 5
CATHODE FOLLOWER NUMBER 6
CATHODE FOLLOWER NUMBER 7
CATHODE FOLLOWER NUMBER 8
120 1w
68
82
36
15k
56k 10%
50
− 15v
+ 15v
GROUNDS
+ 15v
− 15v
− 3.3v
NOTE: 1. ALL RESISTORS ARE ± 5% UNLESS OTHERWISE SPECIFIED
2. UNLESS ALL RESISTORS ARE 0.5w UNLESS OTHERWISE SPECIFIED

Figure 5-1

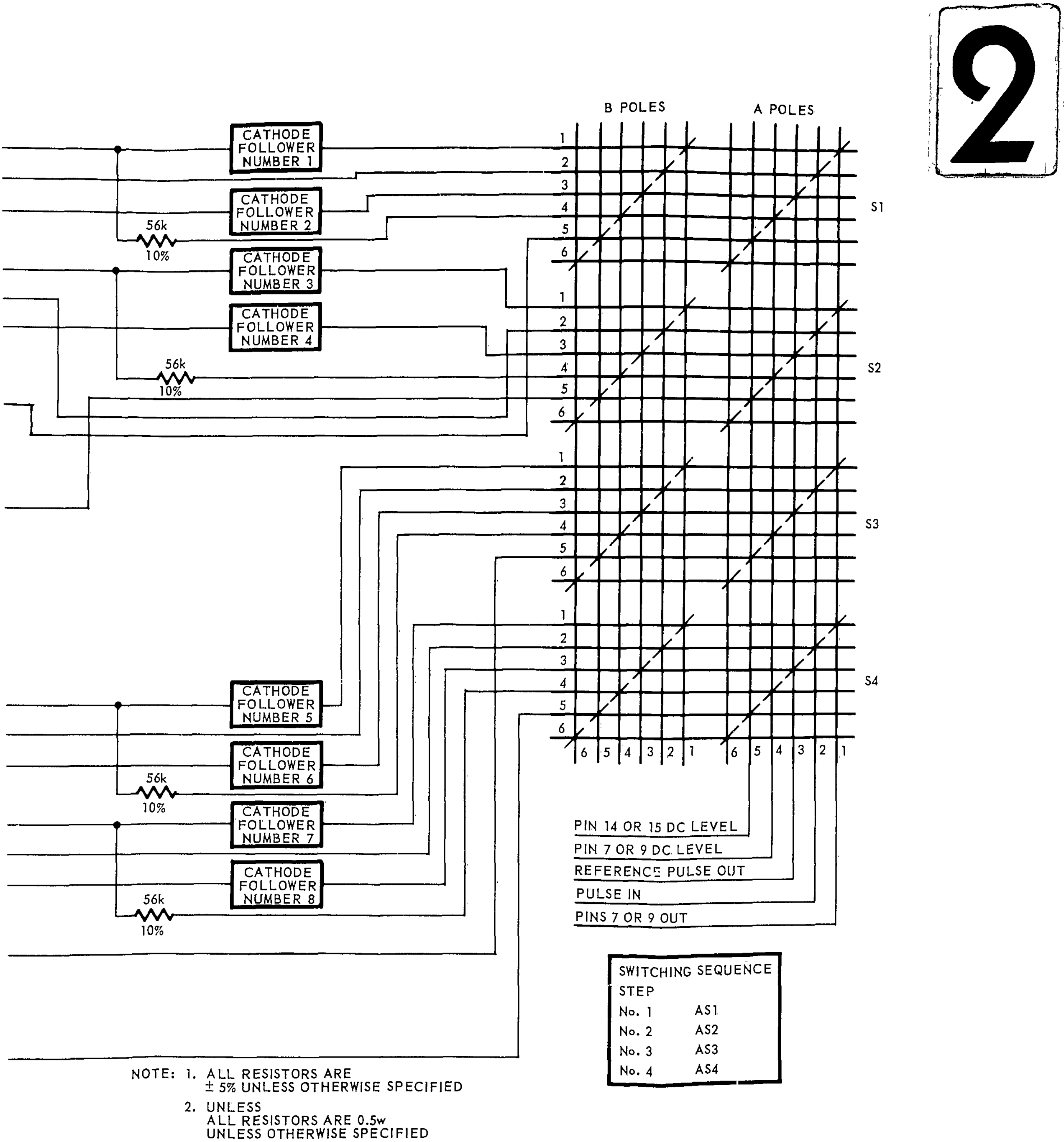


Figure 5-10 Type L Card Instrumentation

Trace C: Pulse output from pin 7 or 9

Trace D: DC output from pin 14 or 15

A typical test photo is shown in Figure 5-3. Some 360 photos were made during the three irradiation runs, and no measurable changes were noted in pulse shapes or DC levels.

SECTION 6

SUMMARY OF WORK TO DATE

A total of 72 circuit cards of twelve types have been tested following either the high or low dose rate curves shown in Figure 3-1 and 3-2. In no instance did the specified gamma ray radiation and temperature environment cause the circuit to operate outside of the acceptance specification limits. Some measurable changes in wave shapes were observed, but they all were small compared to the tolerance allowed. Almost all of the observed changes in waveforms involved the position of the leading or trailing edge of the output. This generally can be attributed to the degree of saturation of the transistor involved. The degree of saturation is related to the gain of the transistor and both increases and decreases of gain have been observed in these transistor types tested in the same environment by NRDL. If transistor gain changes during irradiation, the time required for the transistor to go from saturation to cut off (storage time) will change, and these are probably the kind of effects that were observed. Gain changes can also result in rise and fall time changes, but no changes in these two parameters were noted.

The waveform changes noted in this study would probably not cause any significant changes in the performance of the equipment using these circuits. This conclusion cannot be applied generally to electronic circuits which could encounter this environment. Some characteristics of the circuits tested which seem to minimize these radiation effects are:

1. Most of the circuits were switching circuits and the transistors were operated either in cut-off or in saturation

2. The Class A video amplifier tested had degenerative feedback and so the overall amplifier gain was more a function of the passive component parameters than the active ones

3. The circuits were designed to operate with a wide variation in some of the transistor parameters.

APPENDIX A

SCHEMATICS

On the following pages are the schematics of circuits tested during previous report periods, and also the characteristics of the transistors and diodes used in the twelve circuits of interest in this study.

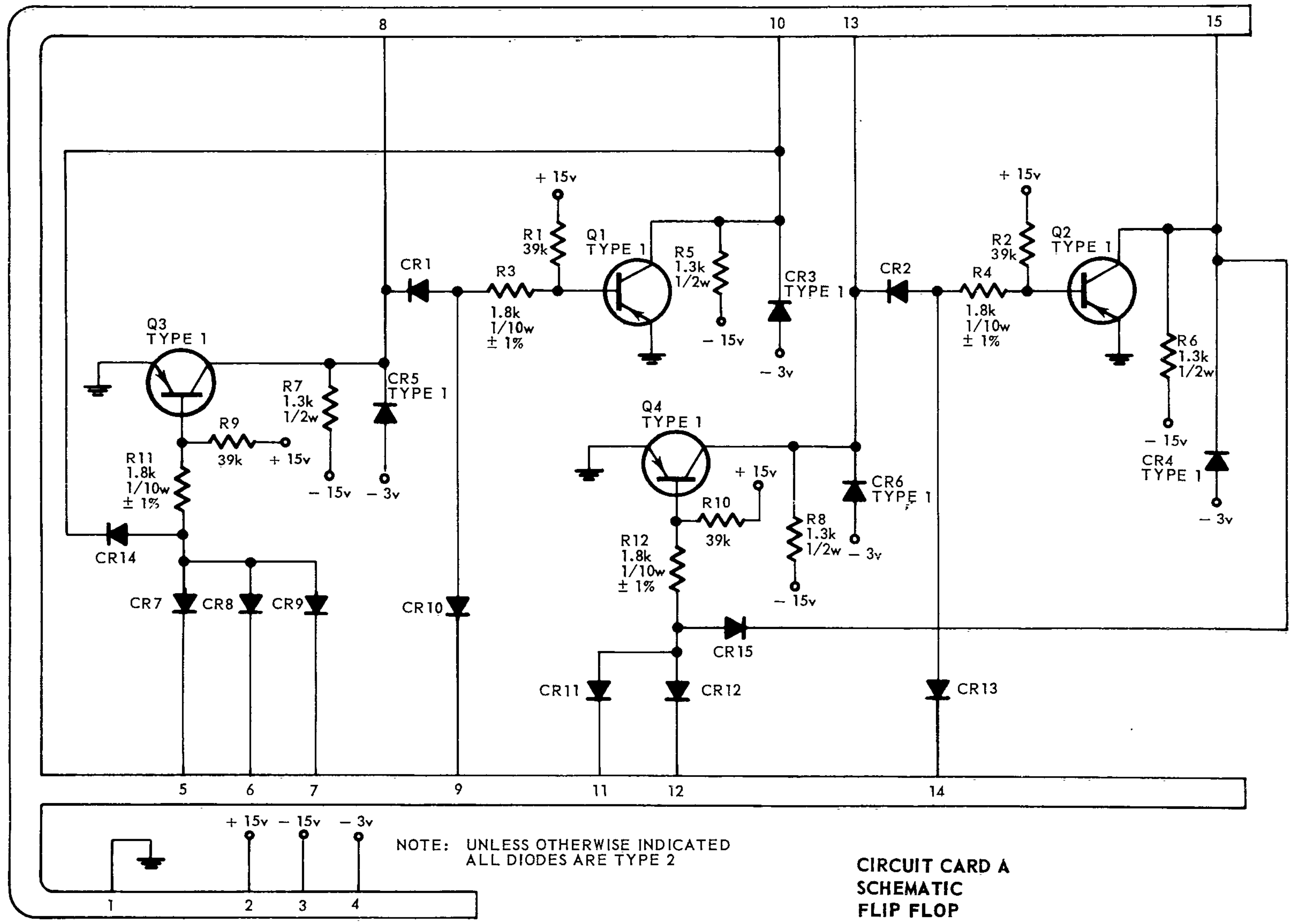


Figure A-1 Flip Flop Schematic

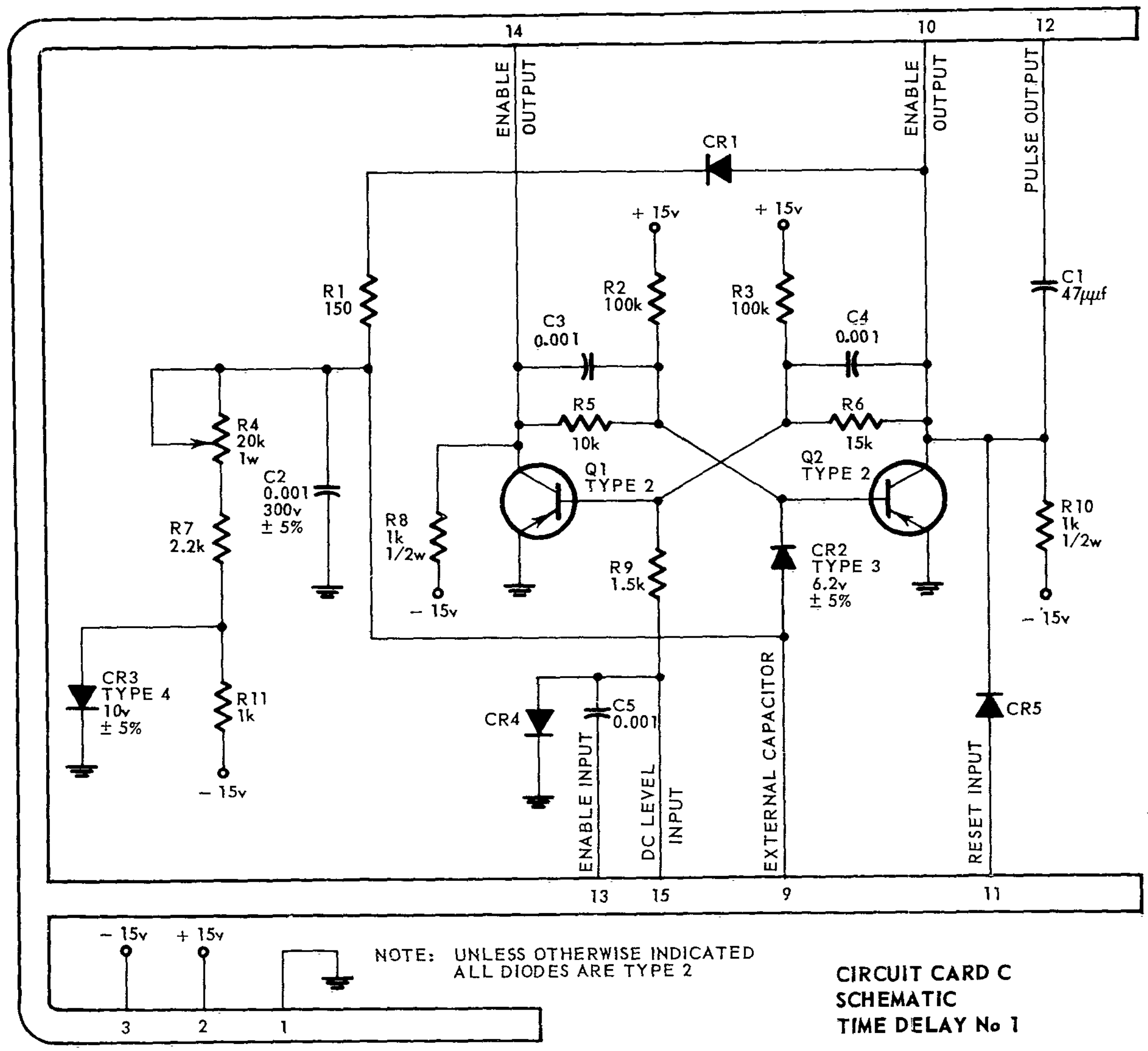


Figure A-2 Time Delay No. 1 Schematic

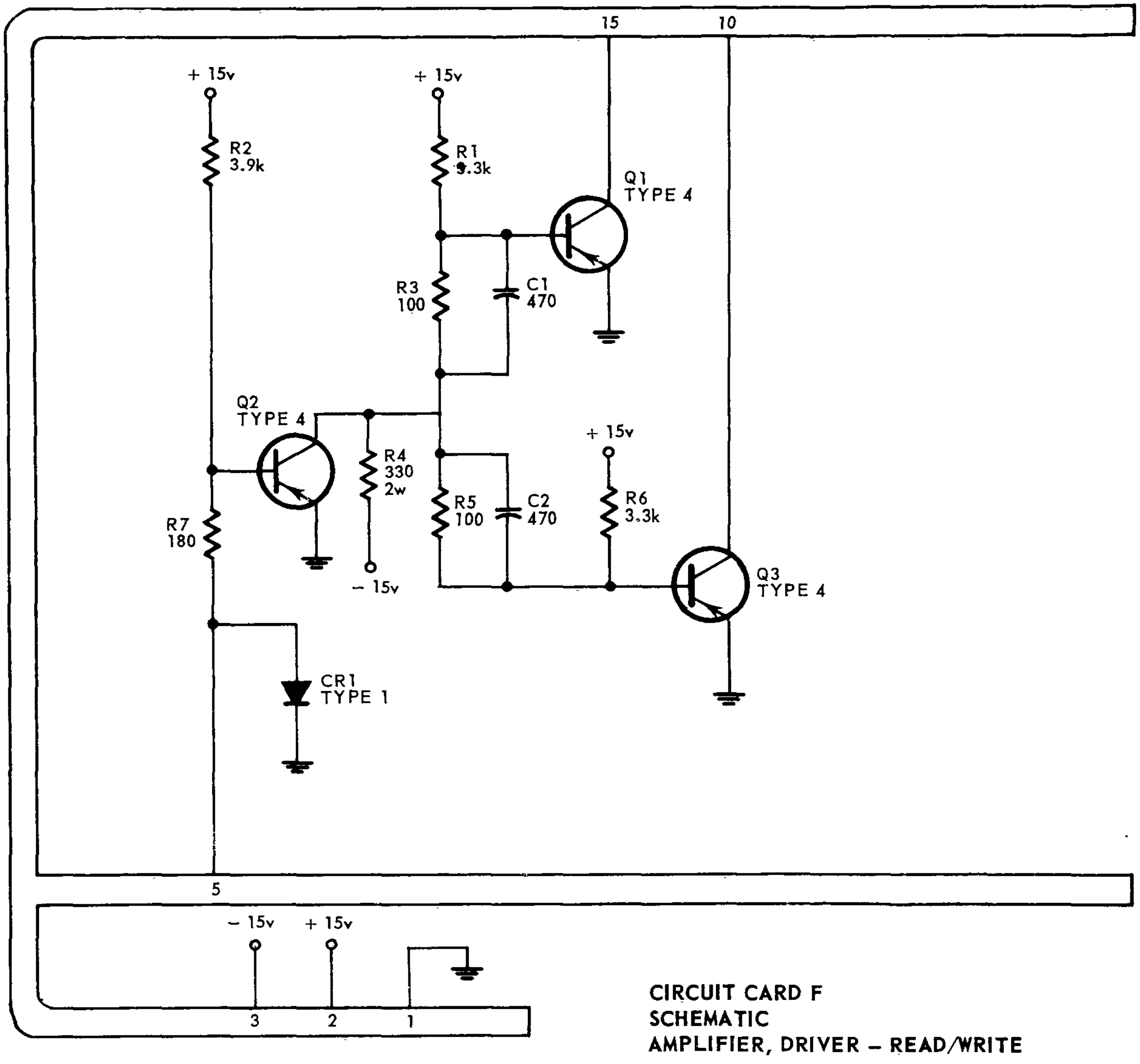


Figure A-3 Amplifier, Driver-Read/Write Schematic

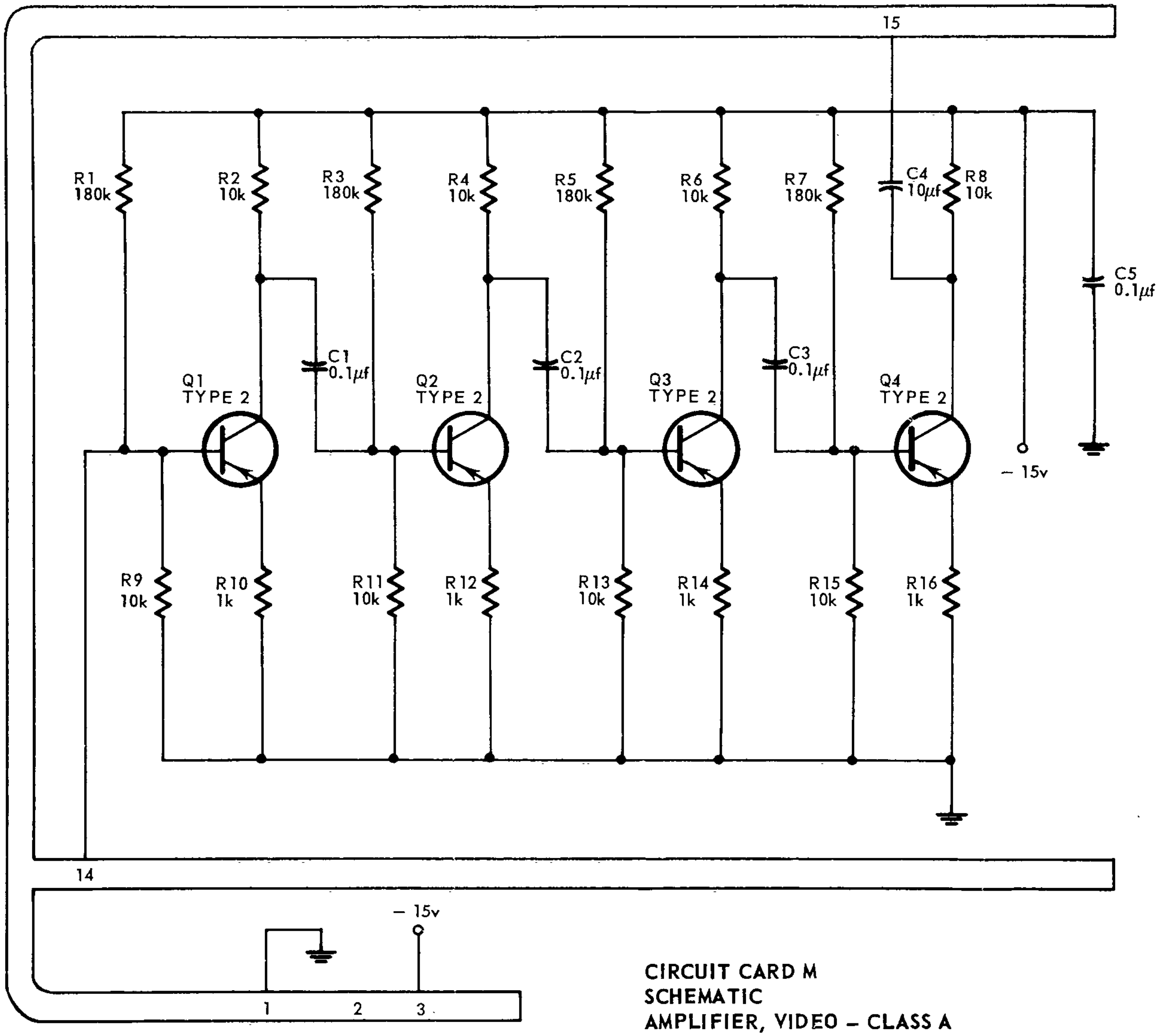


Figure A-4 Amplifier, Video—Class A Schematic

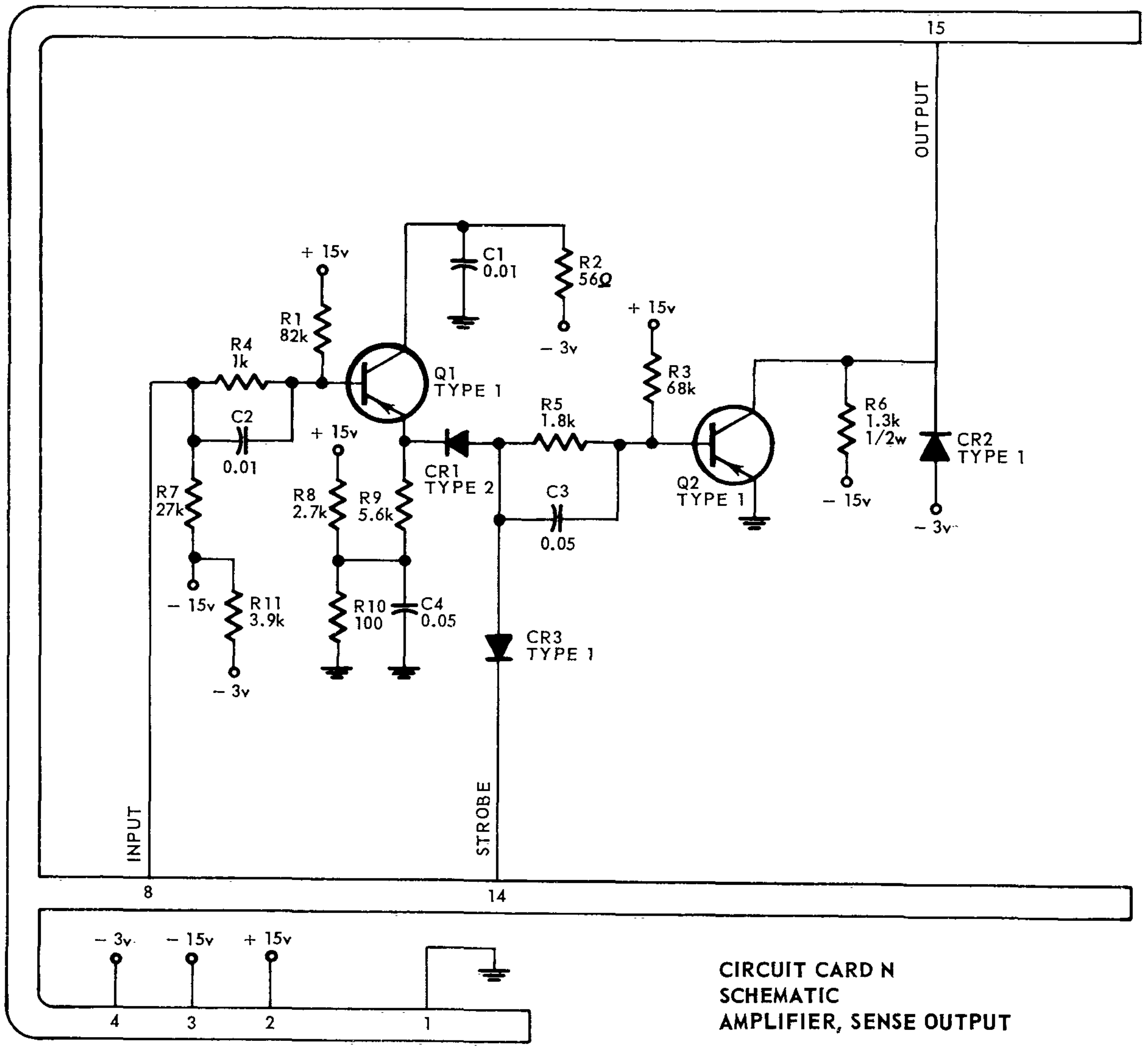


Figure A-5 Amplifier, Sense Output Schematic

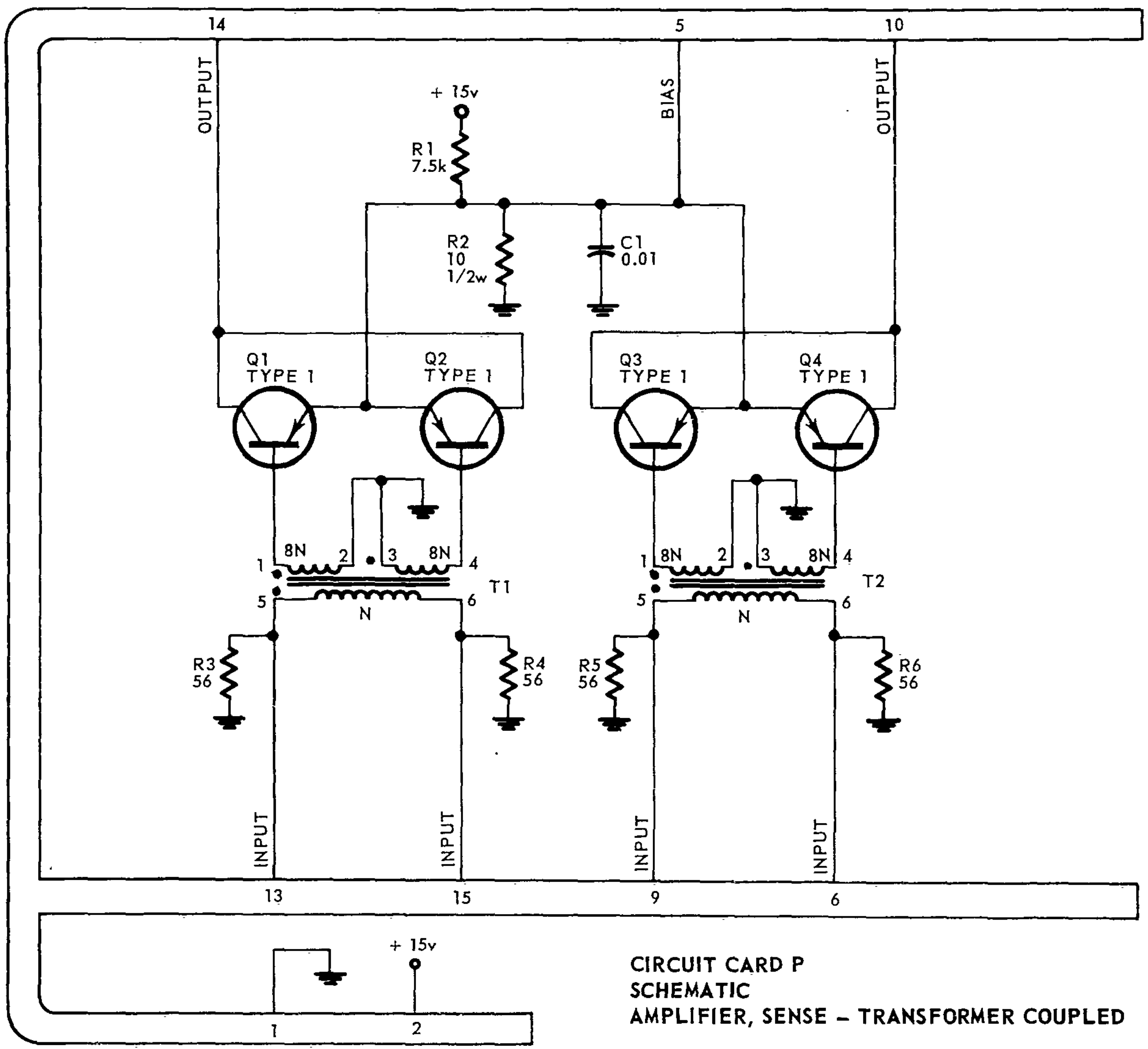


Figure A-6 Amplifier, Sense-Transformer Coupled Schematic

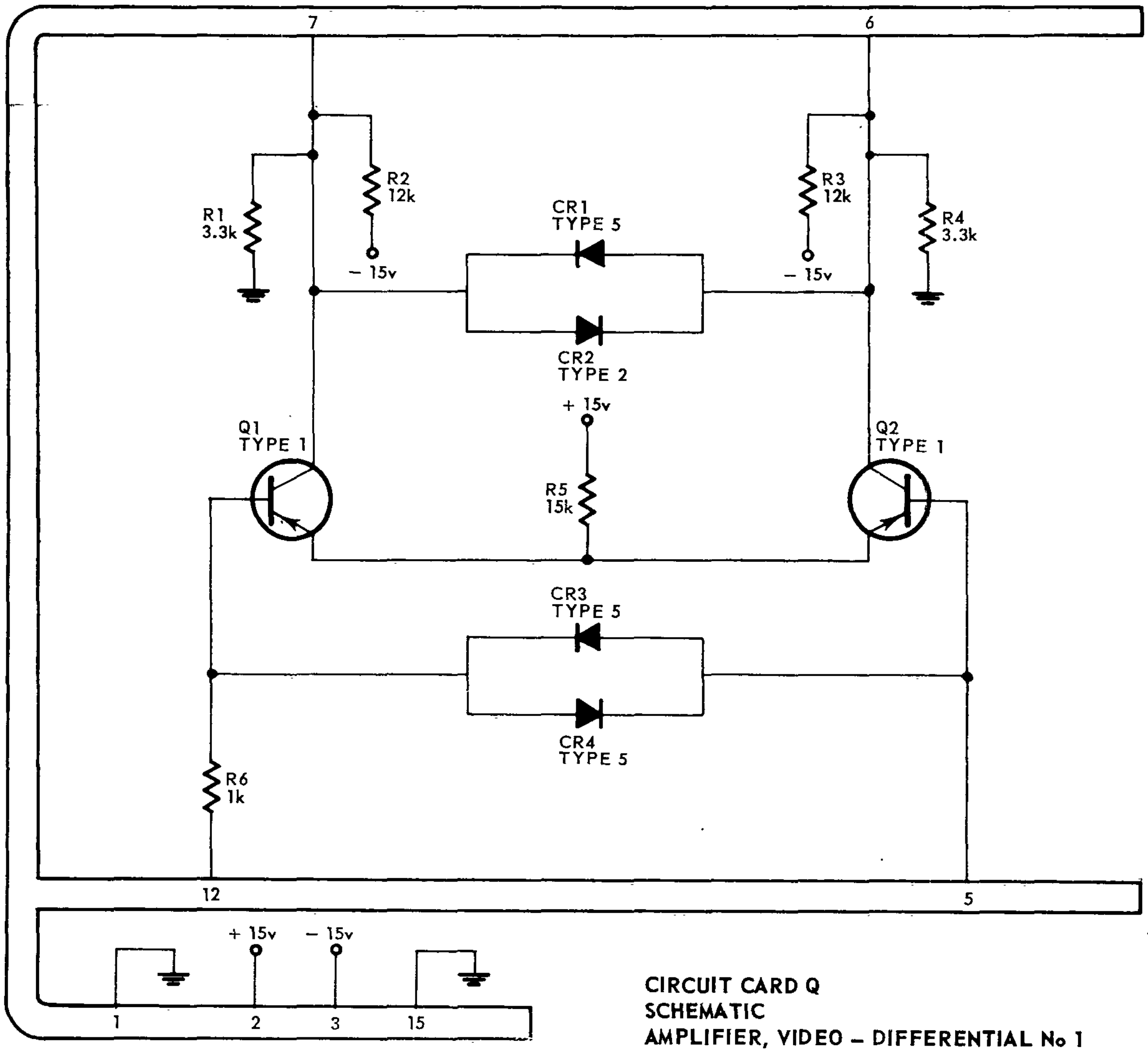


Figure A-7 Amplifier, Video-Differential No. 1 Schematic

TABLE A-1

CHARACTERISTICS

TRANSISTOR TYPE 1

GENERAL

Micro alloy diffused-base transistor specifically designed for very high speed switching applications. The polarities of the emitter and collector are the same as those of homogeneous PNP junction transistors.

PHYSICAL

TO-1 package.

Absolute Maximum Ratings at 25°C

1.	Collector Voltage, V_{CES}	-12V
2.	Collector Voltage, V_{CBO}	-15V
3.	Emitter Voltage, V_{EBO}	-2V
4.	Collector Current, I_C	-50ma DC
5.	Total Device Dissipation at 25°C.	60 mw
6.	Storage Temperature	-65 to +85°C

ELECTRICAL CHARACTERISTICS

			MIN.	MAX.
1.	D. C. gain, h_{FE}	(a) (V_{CE} = -0.3V, I_C = -10ma)	35	130
		(b) (V_{CE} = -0.5V, I_C = -50ma)	20	
2.	I_{CBO}	(a) (V_{CB} = -5V, I_E = 0)		-3 μa
		(b) (V_{CB} = -15V, I_E = 0)		-100μ a
3.	I_{EBO}	(V_{EB} = -1.0V, I_C = 0)		-50 μa
4.	I_{CER}	(V_{CE} = -5V, V_{RBE} = 0.5V, R_B = 10K)		-10 μa
5.	V_{BE}	(I_C = -10ma, I_B = -1.0 ma)		-0.4 v
6.	V_{CE} (SAT)	(I_C = -10ma, I_B = -1.0 ma)		-0.2 v
7.	C_{ob}	(V_{CE} = -3V, I_E = 0, f = 4 mc)		3 pf
8.	Current Amp. Factor h_{fe}	(V_{CE} = -0.5V, I_E = -2ma, f = 20mc)	4.5	
9.	Pulse Response Time with Standard External Circuit	$t_d + t_r$		100 ns
		$t_s + t_f$		120 ns

TABLE A-2

CHARACTERISTICS

TRANSISTOR TYPE 2

GENERAL

Germanium PNP alloy junction transistor. High frequency and fast switching applications.

PHYSICAL

Terminals: Tinned or gold flash
Case: Hermetically sealed-welded metal case

Absolute Maximum Ratings at 25°C

1.	V_{CE} (base cut off with V_{RBE} = 1v, R_B = 100 ohms)		-30V
2.	V_{CBO} (emitter open)		-30V
3.	V_{EBO} (collector open)		-25V
4.	I_c (maximum dc)		-300 ma
5.	Total transistor dissipation	in free air	150 mw
		25° C case temp.	300 mw
6.	Storage Temperature		-65°C to 100° C

ELECTRICAL CHARACTERISTICS at 25 ± 3°C		MIN.	MAX.
1. $h_{FE} = \frac{I_c}{I_B}$ D. C. Beta fwd.	(a) (V_{CE} = -0.35V, I_C=-200 ma)	15	
	(b) (V_{CE} = -0.2V, I_C = -10 ma)	40	
2. I_{CBO} (emitter open, V_{CB} = -30V)			-6 μa
3. I_{EBO} (collector open, V_{EB} = -25V)			-6 μa
4. I_{CER} (V_{CE} = -30V, V_{RBE} = 1V, R_B = 100 ohms)			-30 μa
5. $f_{\alpha fb}$ (forward) (V_{CB} = -5V, I_E = 1 ma)		5 mc	
6. C_{ob} (common base) (f = 1 mc, V_{CB} = -5V, I_E = 0)			20 pf
7. V_{BE}	(a) (I_C= -200 ma, I_B= -13.3 ma)		-0.85v
	(b) (I_C= -10 ma, I_B= -0.5 ma)		-0.35v

TABLE A-3

CHARACTERISTICS

TRANSISTOR TYPE 3

GENERAL

Germanium NPN alloy junction transistor. High frequency and fast switching applications

PHYSICAL

Terminals: Tinned or gold flash
Case: Hermetically sealed-welded metal case.

Absolute Maximum Ratings at 25°C

1.	V_{CE} (base cut off with V_{RBE} = -1V, R_B = 100 ohms)	30 V
2.	V_{CBO} (emitter open)	30 V
3.	V_{EBO} (collector open)	25 V
4.	I_c (maximum dc)	300 ma
5.	Total transistor dissipation (a) in free air	150 mw
	(b) 25°C case temp.	300 mw
6.	Storage Temperature	-65°C to 100°C

ELECTRICAL CHARACTERISTICS at 25 ± 3°C

		MIN.	MAX.
1.	$h_{FE} = \frac{I_C}{I_B}$ DC Beta fwd. (a) V_{CE} = 0.35V, I_C = 200 ma	15	
	(b) V_{CE} = 0.2V, I_C = 10 ma	40	
2.	I_{CBO} (emitter open, V_{CB} = 30 V)		6 μa
3.	I_{EBO} (collector open, V_{EB} = 25 V)		6μ a
4.	I_{CER} (V_{CE} = 30V, V_{RBE} = -1V, R_B = 100 ohms)		30 μ a
5.	$f_{\alpha fb}$ (forward) (V_{CB} = 5V, I_E = -1 ma)	5 mc	
6.	C_{ob} (common base) (f = 1 mc, V_{CB} = 5V, I_E = 0)		20 pf
7.	V_{BE} (I_C = 200 ma, I_B = 13.3 ma)		0.85 V
	(I_C = 10 ma, I_B = 0.5 ma)		0.35 V

TABLE A-4

CHARACTERISTICS

TRANSISTOR TYPE 4

GENERAL

PNP germanium transistor. High current, high speed application

PHYSICAL

Terminals: Tinned or gold flash
Case: Hermetically scaled-welded metal case

Absolute Maximum Ratings at 25° C

1.	V_{CE} (base cut off with $V_{RBE} = 0$, $R_B = 0$)	-20V
2.	V_{CBO} (emitter open)	-20V
3.	V_{EBO} (collector open)	-3V
4.	I_c (maximum dc)	-500 ma
5.	Total transistor dissipation in free air	200 mw
6.	Storage temperature	-62° C to 85° C

ELECTRICAL CHARACTERISTICS AT 25 ± 3°C

		MIN.	MAX.
1.	$h_{FE} = \frac{I_C}{I_B}$ DC Beta fwd. (a) ($V_{CE} = -.5V$, $I_c = -200$ ma)	25	200
	(b) ($V_{CE} = -.4V$, $I_c = -100$ ma)	30	
2.	I_{CBO} (emitter open) (a) $V_{CB} = -20V$		-50μ a
	(b) $V_{CB} = -10V$		-15μ a
3.	I_{EBO} (collector open, $V_{EB} = -3V$)		-1 ma
4.	I_{CER} ($V_{CE} = -20V$, $V_{RBE} = 0$, $R_B = 0$)		-50μ a
5.	C_{ob} (common base, f = 4mc, $V_{CB} = -10V$, $I_E = 0$)		10 pf
6.	V_{BE} ($I_C = -200$ ma, $I_B = -10$ ma)		-0.72V
7.	V_{CE} ($I_C = -200$ ma, $I_B = -10$ ma)		-0.5V
8.	K's (storage time factor) $I_E = 20$ ma		100 ns
9.	Pulse response time with external circuit capacity of 15 pf and $R_C = 50$ ohms. t_r ($I_C = -200$ ma, $I_B = -20$ ma)		50 ns

Input pulse:

t_r = 10 ns max.
width = 8.3 μ sec.
rep. rate = 60 cps
input excursion OV to -10v

TABLE A-5

CHARACTERISTICS

TRANSISTOR TYPE 5

GENERAL

Germanium NPN alloy-junction transistor. High frequency and fast switching applications.

PHYSICAL

Terminals: Tinned or gold flash
Case: Hermetically sealed-welded metal case

Absolute Maximum Ratings at 25°C

1.	V_{CER} (base cut off with V_{RBE} = -1V, R_B = 100 ohms	15V
2.	V_{CBO} (emitter open)	25V
3.	V_{EBO} (collector open)	20V
4.	I_c (maximum dc)	300 ma
5.	Total transistor dissipation in free air	150 mw
6.	Storage temperature	-65°C to 100°C

ELECTRICAL CHARACTERISTICS at 25°C

		MIN.	MAX.
1.	$h_{FE} = \frac{I_C}{I_B}$ DC Beta fwd. (a) V_{CE} = 0.35V, I_c = 200 ma	20	
	(b) V_{CE} = 0.3V, I_c = 100 ma	30	
2.	I_{CBO} (emitter open, V_{CB} = 25V)		6 µa
3.	I_{EBO} (collector open, V_{EB} = 20V)		6 µa
4.	I_{CER} (V_{CE} = 15V, V_{RBE} = -1V, R_B = 100 ohms)		30 µa
5.	C_{ob} (common base) (f = 1 mc, V_{CB} = 5V, I_E = -1 ma)		20 pf
6.	V_{BE} (I_c = 200 ma, I_B = 10 ma)		0.85V
7.	Pulse response time with external circuit capacity of 15 pf and R_c = 75 ohms.		
	$t_1 = (t_d + t_r)$ (I_c = 200 ma, I_B = 13 ma)		0.3 µs
	$t_2 = (t_s + t_f)$ (I_c = 200 ma, I_B = -8 ma)		0.6 µs

Input pulse:

t_r = 10 ns max.
width = 5 µ s
rep. rate = 10 KC
t_f = 10 ns max.
input excursion -4v to + 6.5v

TABLE A-6

CHARACTERISTICS

TRANSISTOR TYPE 6

GENERAL

Germanium PNP alloy-junction transistor. High frequency and fast switching applications.

PHYSICAL

Terminals: Tinned or gold flash
Case: Hermetically sealed-welded metal case.

Absolute Maximum Ratings at 25°C

1.	V_{CE} (base cut off with V_{RBE} = 1V, R_B = 100 ohms)	-15V
2.	V_{CBO} (emitter open)	-25V
3.	V_{EBO} (collector open)	-20V
4.	I_c (maximum dc)	-300 ma
5.	Total transistor dissipation in free air	150 mw
6.	Storage Temperature	-65°C to 100°C

	ELECTRICAL CHARACTERISTICS AT 25°C	MIN.	MAX.
1.	$h_{FE} = \frac{I_C}{I_B}$ DC Beta fwd. (a) V_{CE} = -0.35V, I_c = -200 ma	20	
	(b) V_{CE} = -0.3V, I_c = -100 ma	30	
2.	I_{CBO} (emitter open, V_{CB} = -25V)		-6μ a
3.	I_{EBO} (collector open, V_{EB} = -20V)		-6μ a
4.	I_{CER} (V_{CE} = -15V, V_{RBE} = 1V, R_B = 100 ohms)		-30μ a
5.	C_{ob} (common base, F = 1 mc, V_{CB} = -5V, I_E = +1 ma)		20 pf
6.	V_{BE} (I_c = -200 ma, I_B = -10 ma)		-0.85V
7.	Pulse response time with external circuit capacity of 15 pf and R_c = 75 ohms		
	$t_1 = (t_d + t_r)$ (I_c = -200 ma, I_B = -13 ma)		0.3μ s
	$t_2 = (t_s + t_f)$ (I_c = -200 ma, I_B = +8 ma)		0.6μ s

Input pulse:

t_r = 10 ns max.
width = 5 μ s
rep rate = 10 KC
t_f = 10 ns max.
input excursion + 4V to -6.5V

TABLE A-7

CHARACTERISTICS

DIODE TYPE 1

Maximum Ratings at 25°C

1.	Average Power Dissipation	80 mw
2.	Derating Above 25°C.	1mw/°C.
3.	Ambient Temperature Range	-65°C to + 90°C.
4.	Continuous Inverse Operating Voltage	-20 volts
5.	Continuous D. C. Forward Current	25 ma
6.	Peak Operating Current	100 ma
7.	Surge Current for 1 Second	200 ma

Characteristics at 25°C.

1.	Maximum Forward Voltage at 1 ma		0. 3 volts
2.	Maximum Inverse Current at -3v	(25°C)	4 μa
		(50°C)	25 μ a
3.	Maximum Inverse Current at -20v	(25°C)	20 μ a
		(50°C)	125 μ a
4.	Minimum Inverse Voltage at 1 ma		-28 volts
5.	Reverse Recovery: 256 JAN, 2K, 10pf; 25 ma to -15V	0. 5 μ s	100K
6.	Change Reverse Current and Flutter @ -20v for 10 sec		5 μ a max.

TABLE A-8

CHARACTERISTICS

DIODE TYPE 2

GENERAL

Subminiature glass germanium diode.

Maximum Ratings at 25°C

1.	Average Power Dissipation		80 mw
2.	Derating Above 25°C.		1 mw/°C.
3.	Ambient Temperature Range		-65°C to + 90°C.
4.	Continuous Inverse Operating Voltage		-20 volts
5.	Continuous D. C. Forward Current		25 ma
6.	Peak Operating Current		100 ma
7.	Surge Current for 1 Second		200 ma

Characteristics at 25°C

1.	Maximum Forward Voltage at 1 ma		0.3 volts
2.	Maximum Inverse Current at -3v	(25°C)	4 μa
		(50°C)	25 μa
3.	Maximum Inverse Current at -20v	(25°C)	20 μa
		(50°C)	125 μa
4.	Minimum Inverse Voltage at 1 ma		-28 volts
5.	Reverse Recovery: 256 JAN, 2K, 10pf; 25 ma to -15V		0.5 μs 100K
6.	Change Reverse Current and Flutter @-20v for 10 sec		5 μa max.

TABLE A-9

CHARACTERISTICS

DIODE TYPE 3

GENERAL

Silicon voltage regulator diode.

PHYSICAL

Terminals: Gold plated or tinned copper leads.
Case: Hermetically sealed glass.

Absolute Maximum Ratings at 25°C

1.	Power, Dissipation, Free Air	400 mw
2.	Derating Above 25°C	2.67 mw/°C
3.	Operating Junction Temperature Range	-65°C to 175°C
4.	Storage Temperature Range	-65°C to 175°C
5.	Maximum Current is Determined by the Power Dissipation in Free Air.	

Characteristics at 25°C ± 1.5°C

1.	Breakdown Voltage B_V		6.2V ± 5%
2.	Breakdown Impedance		
		b_z (I_R = 20 ma)	7 ohms max
		b_z (I_R = 2 ma)	250 ohms max
3.	Leakage Current		
		I_R (25°C, V_R = -1.5V)	5 μa max
		I_R (150°C, V_R = -1.5V)	50 μa max
4.	Breakdown Voltage Regulation from	2 ma to 20 ma. ΔB_V	.6V max

TABLE A-10

CHARACTERISTICS

DIODE TYPE 4

GENERAL

Silicon voltage regulator diode.

PHYSICAL

Terminals: Gold plated or tinned copper leads
Case: Hermetically sealed glass

Absolute Maximum Ratings at 25°C

1.	Power Dissipation, Free Air	400 mw
2.	Derating Above 25°C	2.67 mw/°C
3.	Operating Junction Temperature Range	-65°C to 175°C
4.	Storage Temperature Range	-65°C to 175°C
5.	Maximum Current is Determined by the Power Dissipation in Free Air	

Characteristics at 25°C $\pm$ 1.5°C

1.	Breakdown Voltage.	B_V	10.0V $\pm$ 5%
2.	Breakdown Impedance		
		b_z (I_R = 20 ma)	17 ohms max
		b_z (I_R = 2 ma)	50 ohms max
3.	Leakage Current		
		I_R (25°C, V_R = -8.0V)	5 μa max
		I_R (150°C, V_R = -8.0V)	50 μa max
4.	Breakdown Voltage Regulation from 2 ma to 20 ma	ΔB_V	0.3V max

TABLE A-11

CHARACTERISTICS

DIODE TYPE 5

GENERAL

Subminiature glass silicon diode. Switching.

PHYSICAL

Terminals: Gold flash or tinned.
Case: Hermetically sealed glass to lead construction.

Absolute Maximum Ratings at 25°C

1.	Continuous Inverse Voltage	70 V
2.	Continuous DC forward current	400 ma
3.	Power Dissipation in Free Air	400 mw
4.	Storage Temperature	-80°C to 150° C

Characteristics at 25°C

1.	Forward Voltage at 200 ma DC	1.0 V max
2.	Reverse Current at -70v DC	.25 μ a max
3.	Shunt Capacity (E_B= -10V, f= 1mc, E_{RMS}= 1.0V)	10 pf max
4.	Forward Pulse Recovery Time to 1.5 Volts.	150 ns max

Pulse Test Conditions:

(a) Pulse width of 10 μ's
(b) Current pulse rise time .02 μ's
(c) Rep Rate 1 K C
(d) Total series resistance 100 ohms.
(e) Current pulse amplitude 300 ma.

5. Reverse Pulse Recovery Time to 2K. -10V, I_f= 300 ma 500 ns max